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Efforts to total synthesis of philinopside E: convergent synthesis of the sulfated lanostane-type tetraglycoside†

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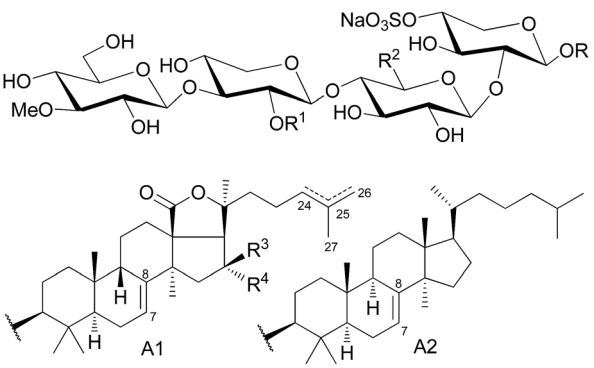
As an important step to total synthesis of philinopside E with important antitumor activities (Ed_{50} 0.75–3.50 μg mL^{-1}), we described herein convergent synthesis of a triterpene glycoside composed of the sulfated tetrasaccharide residue identical to that of philinopside E and the aglycone of lanost-7-en-3β-ol. The stereocontrolled synthesis of the aglycone from 24,25-dihydrolanosterol was accomplished relying on the stereoselective reductions of the 2,3-unsaturated-1,4-diketone system assisted by a C3-*tert*-butyldimethylsilyloxy group and convenient installation of the required 7(8)-double bond *via syn* elimination of triflate. Sequencial convergent coupling of monoglycoside, prepared by reacting the aglycone with orthogonally protected xylosyl thioglycoside, with trisaccharide thioglycoside originated from glucose, xylose and quinovose derivatives, incorporation of sulfation and deprotection afforded the target molecule. The features of our work are that the four 1,2-*trans* glycosidic bonds were stereoselectively constructed and the precious aglycone was introduced in the late-stage synthesis, which would facilitate the total synthesis of philinopside E and related natural products.

Introduction

Triterpene glycosides are a large family of secondary metabolites in plants and marine organisms that have been used in traditional medicines for thousands of years.[1] To date, more than 100 sea cucumber triterpene glycosides have been isolated and characterized.[2] These saponins share a common aglycone skeleton, 3β,20*S*-dihydroxy-5α-lanostano-18,20-lactone. Their oligosaccharide moieties, being frequently sulfated, are composed of several different monosaccharide residues, including D-xylose, D-quinovose, D-glucose, 3-*O*-methyl-D-glucose, and in rare cases, 3-*O*-methyl-D-xylose.[2] Most sea cucumber saponins exhibit potential therapeutic effects in the treatment of cancer, inflammation and infections.[2b,c] Recently, Yi and co-workers[3] isolated four new sulfated saponins, philinopside A, B, E and F, from the sea cucumber *Pentacta quadrangularis*, which is widely distributed throughout the South China Sea (Fig. 1). As a representative of sea cucumber triterpene glycosides, philinopside E exhibits anti-angiogenesis and antitumor activities with Ed_{50} values ranging from 0.75–3.50 μg mL^{-1}.[3b] Studies on its mode of action revealed that philinopside E interacts with the extracellular portion of the kinase insert domain-containing receptor (KDR) to block its interaction with vascular endothelial growth factor (VEGF) and the resultant downstream signaling. This mechanism is distinct from that of conventional small-molecule inhibitors which exclusively target the cytoplasmic kinase domain of KDR.[4] In addition, philinopside E markedly suppresses $\alpha_v\beta_3$ integrin-



Philinopside A: $R^1 = R^4 = H$, $R^2 = CH_3$, $R^3 = OAc$, R = A1, Δ^{24}
Philinopside B: $R^1 = SO_3Na$, $R^2 = CH_3$, $R^3 = OAc$, $R^4 = H$, R = A1, Δ^{25}
Philinopside E: $R^1 = H$, $R^2 = CH_3$, R^3, $R^4 = O$, R = A1, Δ^{25}
Philinopside F: $R^1 = R^4 = H$, $R^2 = CH_2OH$, $R^3 = OAc$, R = A1, Δ^{24}
Target molecule **1**: $R^1 = H$, $R^2 = CH_3$, R = A2

Fig. 1 Structure of philinopside A, B, E, F and target triterpene glycoside **1**.

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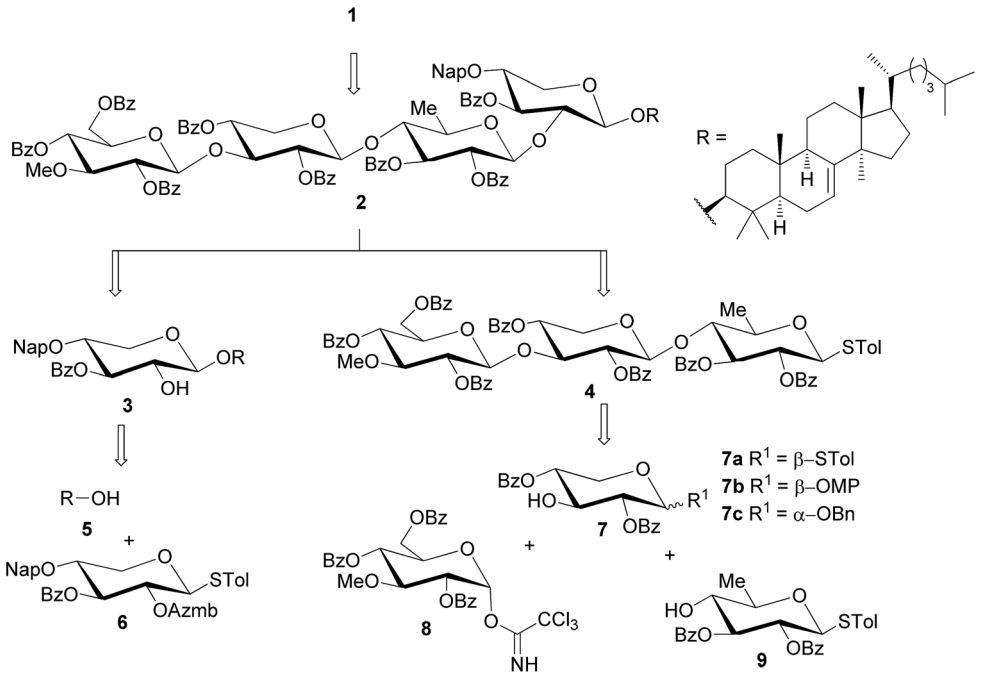
driven downstream signaling.[4] However, further studies were hampered by the limited availability of this natural product. Chemical synthesis has proved to be a powerful tool to make structurally complex saponins of importance in sufficient amounts,[5] however, there is no report on the total synthesis of sea cucumber triterpene glycosides such as philinopside E.[6]

Inspection of philinopside E suggested that a few key problems including construction of sulfated oligosaccharide residue and synthesis of highly multi-functionalized aglycone that have to be solved before a successful total synthesis could be performed. Thus, as the first attempt to gain knowledge about the synthesis of philinopside E, we undertook the synthesis of an analogue of philinopside E, the lanostane-type saponin **1** consisting of the sulfated tetrasaccharide found in philinopside E and the aglycone of lanost-7-en-3β-ol (Fig. 1). We hoped that the developed protecting-group and assembly strategies for stereocontrolled formation of glycosidic bonds and the extension of sugar chain, coupled with the strategies for synthesis of lanost-7-en-3β-ol, would pave a practical way to the total synthesis of philinopside E.

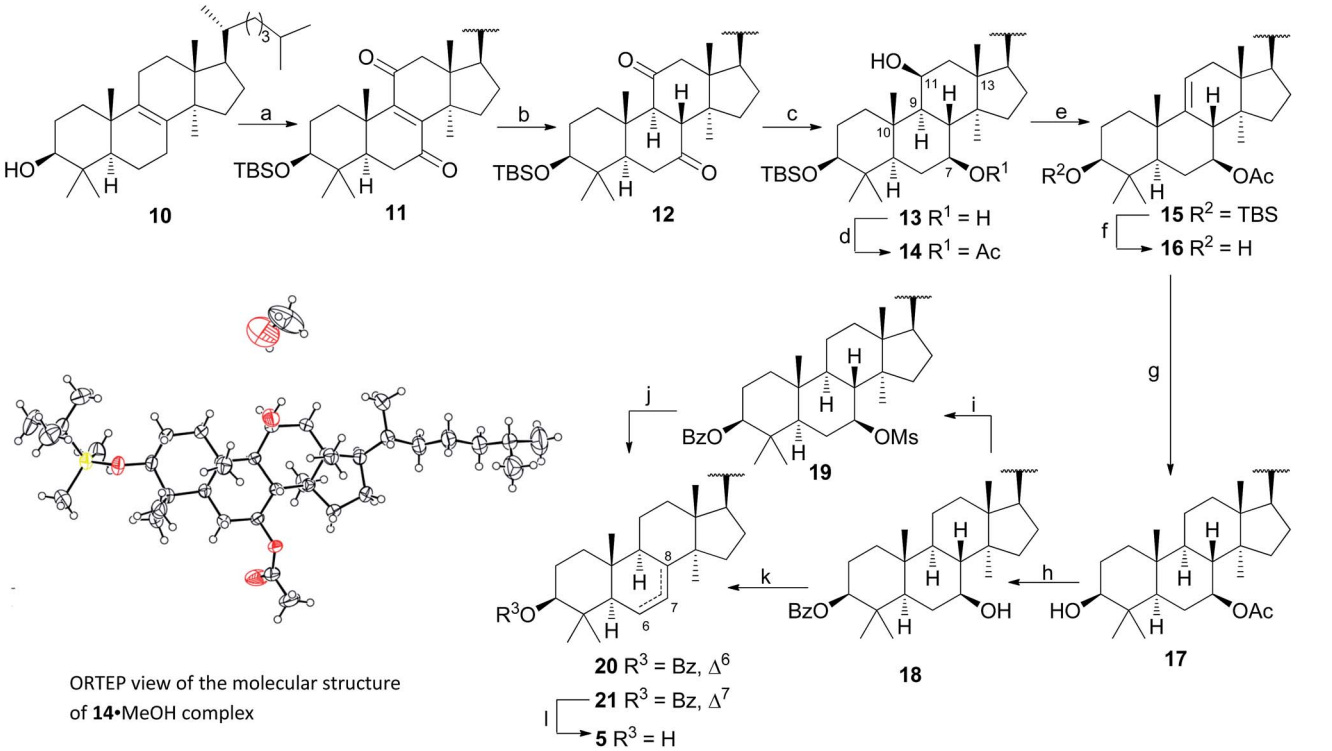
Results and discussion

As shown in Fig. 1, target molecule **1** has four 1,2-*trans* glycosidic bonds and is sulfated at the 4-OH position of the xylose unit. Normally, the formation of 1,2-*trans* glycosidic linkages is facilitated by the participation of neighboring ester protecting groups such as acetate, benzoate, and pivalate,[7] and sulfate groups are introduced in the penultimate step of the synthesis.[8] According to these guidelines, we proposed our plan for the synthesis of saponin **1**. As outlined in Scheme 1, we envisioned that **1** could be obtained by removal of 2-naphthyl methyl (Nap) in **2**, subsequent sulfation of the resulting hydroxyl and global hydrolysis of all the benzoates. The intermediate **2** could be convergently constructed by coupling lanost-7-en-3-yl xyloside **3** with the trisaccharide donor **4**. Monoglycoside **3**, in turn, could be synthesized from lanost-7-en-3β-ol **5** as the aglycone and the orthogonally protected xylosyl donor **6**. Trisaccharide **4** could be prepared by joining three monosaccharide building blocks **7**, **8** and **9**. Benzoate and 2-azidomethyl benzoate are chosen as the protecting groups for the C-2 hydroxyl groups of **6–9** to ensure the highly stereoselective formation of 1,2-*trans* glycosidic linkages. Since the extraction of the aglycone **5** from natural sources such as *Dracaena cinnabari*[9a] and *Azorella trifurcata*[9b] is difficult and there are few methods[10] available to its synthesis, we therefore would prepare the aglycone **5** from 24,25-dihydrolanosterol by designing a new stereoselective route.

The synthesis of saponin **1** commenced with the synthesis of **5** en route to monoglycoside **3** (Scheme 2). Thus, *tert*-butyldimethylsilyl (TBS) protection of the 3-OH of 24,25-dihydrolanosterol **10** (ref. 11) under the forcing conditions, followed by allylic oxidation with $KMnO_4$ in the presence of 18-crown-6 (ref. 12) afforded the unsaturated ketone **11** in 67% yield over two steps. After that, conjugate reduction of **11** with zinc dust in refluxing acetic acid[11] gave diketone **12** in an excellent 96% yield. Simultaneous reduction of two carbonyl groups in **12** by $LiAlH_4$ led to diol **13** as the single product in 85% yield. Notably, bulky TBS is crucial for the highly stereoselective reduction of diketone **12** because the congeners of **12** with tetrahydropyranyl and acetyl groups as the protecting



Scheme 1 Retrosynthetic analysis of target triterpene glycoside **1**.



Scheme 2 Preparation of the aglycone **5**. Reagents and conditions: (a) (i) TBSCl, imidazole, *N*,*N*-dimethylformamide, 45 °C, 5 h; (ii) $KMnO_4$, 18-crown-6, CH_2Cl_2/H_2O, 18 °C, 24 h, 67% for two steps; (b) zinc dust, AcOH, 120 °C, 2 h, 96%; (c) $LiAlH_4$, THF, 13 °C, 3 h, 85%; (d) Ac_2O, pyridine, DMAP, 17 °C, overnight, 91%; (e) MsCl, Et_3N, CH_2Cl_2, 15 °C, 89%; (f) HF·pyridine, THF, 40 °C, 88%; (g) H_2 (130 atm), Pd/C, AcOH, MeOH, 120 °C, 72 h, 95%; (h) (i) BzCl, pyridine, DMAP, 18 °C, 6 h; (ii) AcCl, $CHCl_3$/MeOH, 40 °C, 24 h, 78% for two steps; (i) MsCl, Et_3N, CH_2Cl_2, 13 °C, 5 h, 87%; (j) NaOAc, AcOH, 120 °C, 0.5 h, 87% (**20**/**21** = 1/12.5); (k) Tf_2O, pyridine, CH_2Cl_2, −10 °C, 5 h, 96% (**20**/**21** = 1/20); (l) $LiAlH_4$, THF, 21 °C, 4 h, 89%.

group of 3-OH led to a diastereomeric mixture by reducing the carbonyl groups.[13] By treating **13** with acetic anhydride in pyridine with *N*,*N*-dimethyl pyridine (DMAP) as a catalyst acetate **14** was obtained with a 91% yield. The absolute stereochemistry of **14** was unambiguously confirmed by X-ray crystallographic analysis (Scheme 2).[14]

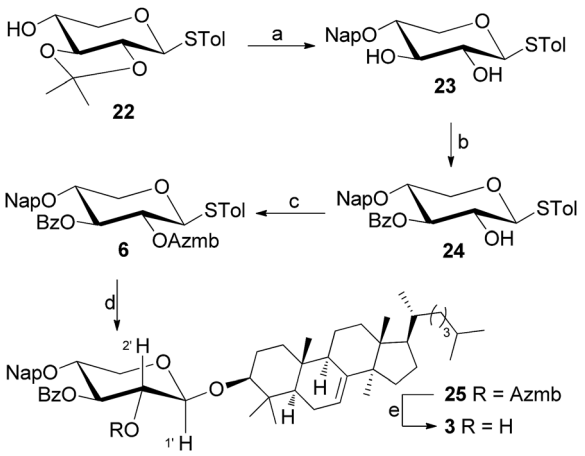
On the basis of the crystal structure, the synthesis of **14** deserves some comments. The ORTEP view of the crystal illustrates that two angular methyl groups at C-10 and C-13 are both β-oriented, which can cause steric hindrance to 11β-OH on the same face of the rings. This explains why the acetylation of diol **13** preferentially occurred to the 7β-OH. It should be also pointed out that in ^{1}H NMR spectrum of **14** the axial 7α-H resonates at 4.91 ppm as a doublet of triplets, while the equatorial 11α-H appears at 4.22 ppm as a broad singlet. These splitting patterns can be predicted by Karplus equation[15] on the basis of stereochemical assignment of **14**. The same trends were observed for 7α-H and 11α-H in **13**.

With the access to **14** secured, we initially sought to remove the equatorial 11β-OH through a Barton–McCombie radical deoxygenation reaction[16] which involves conversion of the alcohol to a xanthate, followed by reduction with tri-*n*-butyltin hydride in refluxing toluene. However, subjecting the alcohol **14** to the standard conditions did not afford the xanthate required for the deoxygenation step. Inspired by the work of Deslongchamps *et al.*,[17] we then tended to use the $LiAlH_4$ reduction of mesylate to remove the 11β-OH. Unexpectedly, treatment of alcohol **14** with mesyl chloride and triethyl amine resulted in the formation of alkene **15** (Scheme 2), which is probably caused by the elimination of the mesylate generated *in situ*. The ready availability of alkene **15** led to an alternative strategy for removing the 11β-OH, namely, hydrogenation of the 9(11)-double bond in **15**. After many attempts, we found that the presence of the bulky TBS group at the C-3 position significantly hampered the hydrogenation reaction. This issue can be simply solved by removing the TBS group. After deprotection, alcohol **16** could undergo hydrogenation under 130 atmospheric pressures at 120 °C to provide **17** in an excellent 95% yield.

With alcohol **17** in hand, we turned our attention to the synthesis of **5** by a *syn* elimination (Scheme 2). Thus, benzoylation of the 3-OH followed by a facile chemoselective deacetylation using methanolic hydrogen chloride[18] afforded alcohol **18**. Inspired by the synthetic work of Purdy and co-workers,[19] who utilized *syn* elimination of mesylate to form the desired double bond, mesylate **19**, prepared by mesylation of **18**, was treated with sodium acetate in refluxing acetic acid to furnish a mixture of olefins **20** and **21** in 87% yield with a ratio of 1/12.5. The ratio was determined by ^{1}H NMR spectroscopy based on comparing integration values for the H-7 of **20** (5.53 ppm) and **21** (5.22 ppm). It is well established that triflate is a better leaving group than mesylate,[20] and triflates have been widely used in formation of double bonds in steroids.[21]

Consequencely, in order to improve the regioselectivity of the elimination reaction, **18** was converted into a triflate using triflic anhydride and pyridine in CH_2Cl_2, which underwent rapid elimination to form **21** with an exclusive selectivity (**20**/**21** = 1/20). This result implies that an E1 mechanism might be responsible for the elimination of triflate. Finally, reductive deprotection of benzoate with $LiAlH_4$ supplied **5** in 89% yield, ^1H data of which are identical to the reported.[22] Thus the transformation of 24,25-dihydrolanosterol into **5** was achieved in 12 steps with an overall 24% yield.

With the aglycone **5** in hand, it is necessary to synthesize pyranoxylosyl donor **6** to make monoglycoside **3**. Briefly, Nap protection of the 4-OH in thioglycoside **22** (ref. 23) followed by removal of isopropylidene with methanol in the presence of camphorsulfonic acid (CSA) furnished diol **23** with a 96% yield over two steps. Dibutylstannylene-mediated regioselective benzoylation[24] of **23** afforded benzoate **24** in a satisfactory 60% yield. Condensation of alcohol **24** with 2-azidomethyl benzoic acid (AzmbOH) in the presence of 1-ethyl-3-(3-dimethylaminopropyl)-carbodiimide hydrochloride (EDCI) gave the xylosyl thioglycoside **6**. The glycosylation of **5** with **6** promoted by *N*-iodosuccinimide (NIS) and trimethylsilyl triflate (TMSOTf) proceeded smoothly to furnish **25** in 91% yield. Notably, this procedure left the 7(8)-double bond on **5** intact. The newly formed 1,2-*trans* glycosidic linkage on **25** is confirmed by the coupling constant of $^3J_{H1'-H2'} = 7.0$ Hz. In addition to allowing for the selective formation of 1,2-*trans* glycosidic bonds through neighboring group participation, Azmb is often used as a temporary protecting group in carbohydrate synthesis because it can be selectively removed in the presence of other acyl groups including benzoyl group (Bz).[25] As expected, the Azmb group on **25** was selectively cleaved in the presence of a Bz group by first reducing the azide with Bu_3P and then intramolecular aminolysis of benzoate[25] to give alcohol **3** in 92% yield (Scheme 3).

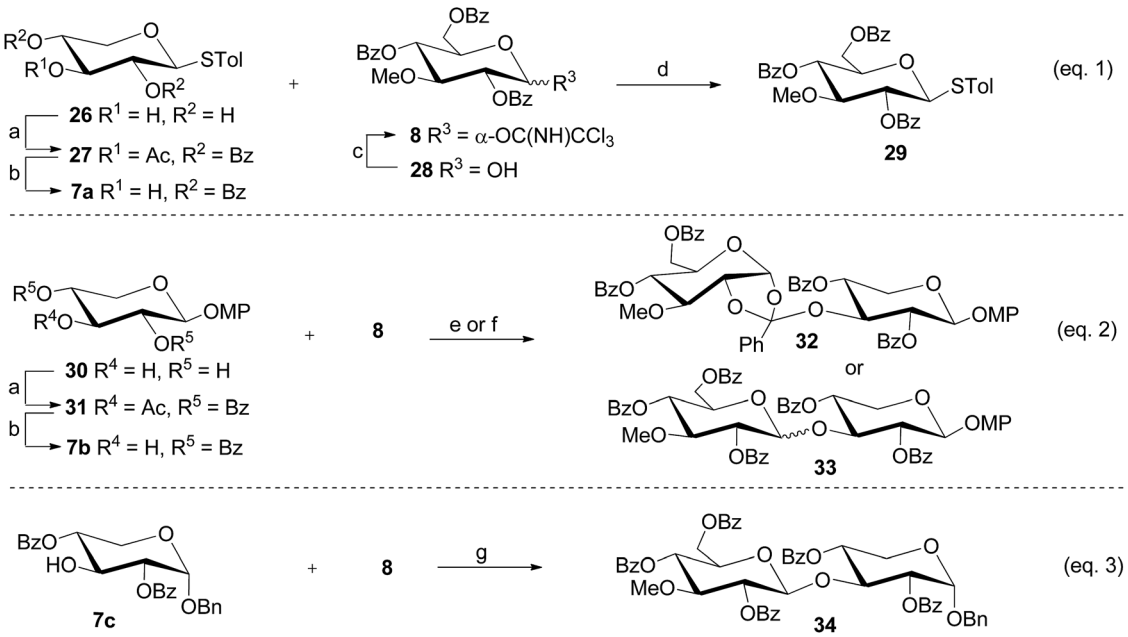


Scheme 3 Synthesis of monoglycoside **3**. Reagents and conditions: (a) (i) NapBr, NaH, *N*,*N*-dimethylformamide, 27 °C, 6 h; (ii) CSA, CH_2Cl_2/MeOH, 28 °C, 5 h, 96% for two steps; (b) (i) Bu_2SnO, toluene, 120 °C, 2 h; (ii) BzCl, 0 °C, 5 h, 60%; (c) AzmbOH, EDCI, DMAP, CH_2Cl_2, 13 °C, 11 h, 91%; (d) **5**, NIS, TMSOTf, CH_2Cl_2, 4 Å molecular sieves, 0 °C, 2 h, 91%; (e) Bu_3P, H_2O, THF, 50 °C, 1 h, 92%.

With the synthesis of **3** fully realized, the next significant step as outlined in Scheme 1 for convergent synthesis of **1** is the extension of the sugar chain on **3** by trisaccharide donor **4**. It was initially expected that thioglycoside **4** could be assembled by a reaction sequence involving coupling of xylosyl acceptor **7a** with the trichloroacetimidate donor **8**, transformation of the resultant disaccharide into the corresponding imidate and subsequent glycosylation with thioglycoside **9**. For this purpose, **7a** was synthesized by first selective acetylation[26] of the 3-OH of thioglycoside **26**,[23] benzoylation of both 2-OH and 4-OH, and final removal of the acetyl group with methanolic hydrogen chloride.[18] Glucosyl trichloroacetimidate **8** was then prepared from hemiacetal **28**.[27] After that, TMSOTf-promoted glycosylation of **7a** with **8** was performed. Disappointingly, the reaction did not produce any of the desired disaccharide and only gave glucosyl thioglycoside **29** in 56% yield (Scheme 4 eqn (1)). From this observation, we assumed that the vicinal electron-withdrawing benzoates render the 3-OH of **7a** significantly less nucleophilic than the anomeric thioether of the same molecule. Thus aglycone transfer[28] of thioglycoside **7a** preferentially occurred in the reaction.

To circumvent this unexpected aglycone migration, *p*-methoxyphenyl (PMP) group, being less nucleophilic than phenylthio group, was introduced as an anomeric protecting group of xylosyl acceptor. In an analogous route to that of **7a**, xylosyl acceptor **7b** was obtained from **30**.[29] Unfortunately, upon treatment of **7b** with **8** in the presence of TMSOTf (0.1 equiv.), orthoester **32** was obtained in 35% yield (Scheme 4 eqn (2)). By switching the activation agent from TMSOTf to *tert*-butyldimethylsilyl triflate (TBSOTf) (0.3 equiv.), the reaction did produce the desired β-linked disaccharide **33β** in 39% yield, but along with α-isomer **33α** in 23% yield. Although it is often disfavored by the presence of a neighboring participatory substituent at the C-2 position of the glycosyl donor, the formation of 1,2-*cis* glycosidic linkages is not unknown in similar reactions.[7,30] The formation of undesired **33α** was ascribed to the decreased reactivity of 3-OH due to intramolecular hydrogen-bond between the anomeric PMP with 3-OH on **7b**. ^1H NMR data of **7b** demonstrates that **7b** partially adopts a $^1C_4$ chair conformation, thus offering opportunities for intramolecular hydrogen-bond formation. ^1H NMR studies[31] and theoretical calculations[32] on molecules similar to **7b** lend support to those inferences.

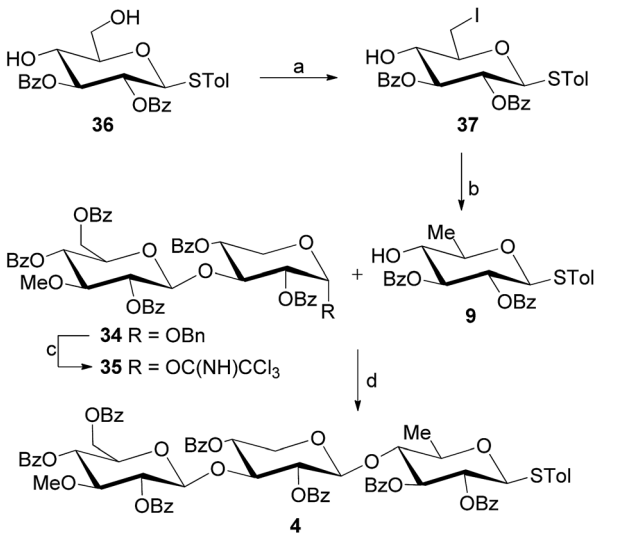
Not satisfied with the relatively poor stereochemical outcome of the reaction of **7b** with **8**, we sought another approach to the desired disaccharide. Previous work by other groups[33] illustrates that benzyl α-xylosides with 3-OH free are competent glycosyl acceptors in a wide variety of glycosylation events. On the basis of these results, TMSOTf-promoted coupling of benzyl α-xyloside **7c** (ref. 24b) with trichloroacetimidate **8** was conducted. Happily, this reaction afforded the desirable disaccharide **34** in 80% yield (Scheme 4 eqn (3)). Conversion of benzyl glycoside **34** into disaccharide trichloroacetimidate **35** was achieved by removing the benzyl group of **34** with hydrogenolysis and subsequently treating the resultant alcohol with trichloroacetonitrile in the presence



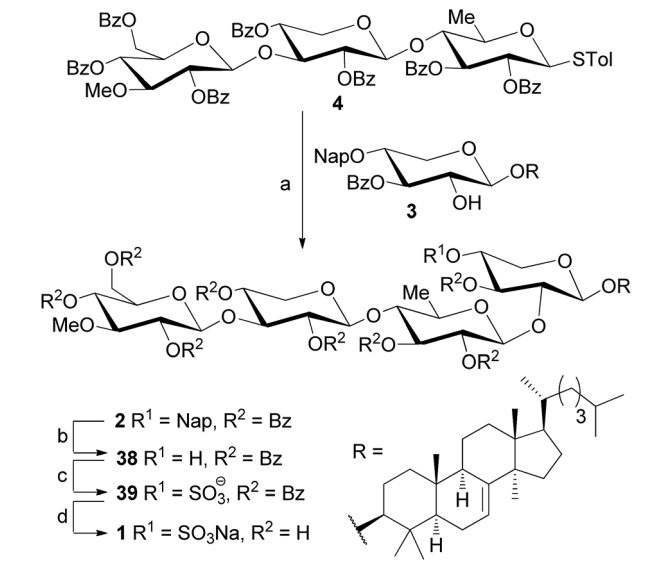
Scheme 4 Preparation of disaccharide **34**. Reagents and conditions: (a) (i) Ac_2O, TBAOAc, CH_3CN, 40 °C, 6 h; (ii) BzCl, pyridine, DMAP, 25 °C, 4 h, 59% for **27**, 60% for **31**; (b) AcCl, CH_2Cl_2/MeOH, 26 °C, 24 h, 95% for **7a**, 93% for **7b**; (c) Cl_3CCN, DBU, CH_2Cl_2, 25 °C, 8 h, 95%; (d) TMSOTf (0.1 equiv.), 4 Å molecular sieves, CH_2Cl_2, 0 °C, 1 h, 56%; (e) TMSOTf (0.1 equiv.), 4 Å molecular sieves, CH_2Cl_2, 0 °C, 1 h 35% for **32**; (f) TBSOTf (0.3 equiv.), 4 Å molecular sieves, CH_2Cl_2, 0 °C, 1 h, 39% for **33β**, 23% for **33α**; (g) TMSOTf, 4 Å molecular sieves, CH_2Cl_2, 0 °C, 1 h, 80%.

of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) (Scheme 5). Gratifyingly, coupling of **35** and quinovosyl thioglycoside acceptor **9** proceeded smoothly providing the expected trisaccharide thioglycoside **4** in 70% yield. Thioglycoside **9**, in turn, could be readily prepared by selective iodination of primary hydroxyl of **36** (ref. 34) using Ph_3P/I_2/imidazole and the following deiodination of the resulting **37** by hydrogenolysis.

With key two building blocks **3** and **4** available, the synthesis of our target molecule **1** was in sight. As shown in Scheme 6, NIS-promoted reaction of **3** and **4** in the presence of TMSOTf gave rise to the tetrasaccharide saponin **2** in a satisfactory 67% yield. Oxidative removal of the Nap group was then effected by 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in MeOH/CH_2Cl_2 to give alcohol **38** in 88% yield. Using pyridine·SO_3 as



Scheme 5 Synthesis of trisaccharide **4**. Reagents and conditions: (a) PPh_3, imidazole, I_2, THF, 29 °C, 1 h; (b) H_2, 10% Pd–C, $NaHCO_3$, *N*,*N*-dimethylformamide, 40 °C, 24 h, 83%; (c) (i) H_2, 10% Pd/C, EtOH, 50 °C, 24 h; (ii) Cl_3CCN, DBU, CH_2Cl_2, 5 h, 74% for two steps; (d) TMSOTf, 4 Å molecular sieves, CH_2Cl_2, 0 °C, 1 h, 70%.



Scheme 6 Synthesis of saponin **1**. Reagents and conditions: (a) NIS, TMSOTf, CH_2Cl_2, 4 Å molecular sieves, 2 h, 0 °C, 67%; (b) DDQ, CH_2Cl_2/MeOH, 20 °C, 5 h, 88%; (c) pyridine·SO_3, pyridine, microwave, 100 W, 100 °C, 2 h, 94%; (d) NaOMe, MeOH, 25 °C, 24 h, 86%.

the sulfating agent, sulfated product **39** was then obtained in an excellent 94% yield by microwave-assisted sulfation[35] of **38** in pyridine at 100 °C. After treatment of **39** with MeONa in methanol to globally deprotect benzoyl groups and subsequent dialysis against water, target molecule **1** was finally obtained. ^{1}H and ^{13}C spectroscopic data due to the tetrasaccharide moiety of **1** match those of philinopside E.

Conclusions

In conclusion, a tritepene saponin, comprised of the same tetrasaccharide residue as that of philinopside E and the aglycone of lanost-7-en-3β-ol, has been accomplished by a convergent coupling of trisaccharide thioglycoside donor with monoglycoside acceptor. Lanost-7-en-3β-ol was efficiently prepared from commercially available 24,25-dihydrolanosterol in a stereocontrolled manner involving stereoselective reduction of unsaturated 1,4-diketone system and facile installation of 7(8)-double bond by *syn* elimination of triflate. The successful access to trisaccharide thioglycoside demonstrated that a benzyl α-xyloside was a critical glycosyl acceptor for the extension of sugar chain at its 3-OH. Since the sugar fragment of philinopside E is found in more than 40 sea cucumber triterpene glycosides,[2,3] the protecting-group and assembly tactics in this work, used to stereoselectively construct glycosidic linkages and to extend sugar chain, sets the foundation for the synthesis, structural modification and biological evaluation of philinopside E and its congeners.

Experimental

General information

All nonaqueous reactions were carried out under an atmosphere of argon in flame- or oven-dried glassware with magnetic stirring unless otherwise indicated. Dichloromethane for glycosylation reactions was distilled from calcium hydride. All other commercially obtained reagents were used as received, except where specified otherwise. Flash column chromatography was performed on Silica Gel H (300–400 mesh, Qingdao, China). Analytical thin layer chromatography was performed on Silicycle SiliaPlate glass-backed plates coated with silica gel (60 Å pore size, F-254 indicator) and visualized by exposure to ultraviolet light and/or staining with aqueous 8% sulfuric acid in methanol. Optical rotations were determined with a digital polarimeter. High-resolution mass spectral (HRMS) data were determined with a LTQ Orbitrap. ^{1}H and ^{13}C NMR spectra were recorded on a 500 or 600 MHz NMR spectrometer with Me_4Si as the internal standard. Chemical shifts are recorded in δ values and J values were given in Hz.

3β-(*tert*-Butyldimethylsilyloxy)-lanost-8-en-7,11-dione (11)

To a solution of **10** (3.70 g, 8.63 mmol) in *N*,*N*-dimethylformamide (12 mL) were added TBSCl (2.60 mL, 17.26 mmol) and imidazole (2.07 g, 34.52 mmol). After the reaction mixture was warmed at 45 °C, and stirred for 5 h, the volatile was evaporated *in vacuo*. The residue was taken up in CH_2Cl_2 and washed with 1 M HCl, saturated aqueous $NaHCO_3$ and brine. The collected organic phase was dried over Na_2SO_4, filtered, and concentrated under the reduced pressure. The resultant crude product was used next step. A 100 mL round bottom flask open to atmosphere was charged with $KMnO_4$ (1.16 g, 7.37 mmol) and 18-crown-6 (1.95 g, 7.37 mmol), followed by the addition of 30 mL of water. A solution of the obtained above product in 30 mL of CH_2Cl_2 was then added to the resulting suspension by a quick syringe transfer. The reaction mixture was vigorously stirred under argon at rt for 24 h, then the solid was filtered off with a Buche funnel and washed with CH_2Cl_2. The filtrate was separated, and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4, filtered and concentrated. The residues were purified by silica gel column chromatography (petroleum ether/CH_2Cl_2 = 3/1) to give **11** (478 mg, 0.84 mmol, 67% for two steps). $[\alpha]_D^{24}$ = +56.4 (*c* 1.10, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.23 (dd, J = 11.4, 4.3 Hz, 1H), 2.88–2.78 (m, 1H), 2.73 (d, J = 16.0 Hz, 1H), 2.59 (d, J = 16.0 Hz, 1H), 2.56–2.40 (m, 2H), 2.21–2.07 (m, 1H), 2.03–1.90 (m, 1H), 1.29 (s, 3H), 1.16 (s, 3H), 0.93 (s, 3H), 0.91–0.84 (m, 18H), 0.84 (s, 3H), 0.80 (s, 3H), 0.03 (s, 3H), 0.02 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.70, 202.65, 152.2, 150.7, 78.4, 51.9, 50.4, 49.3, 49.1, 47.5, 39.9, 39.6, 39.5, 36.9, 36.4, 36.3, 34.2, 32.4, 28.4, 28.2, 28.1, 27.5, 26.02, 26.00, 24.1, 23.0, 22.7, 18.7, 18.2, 17.8, 17.0, 16.1, −3.6, −4.8; HRMS (ESI): *m*/*z* calcd for $C_{36}H_{63}O_3Si$ $[M + H]^+$ 571.4541, found 571.4538.

3β-(*tert*-Butyldimethylsilyloxy)-lanost-7,11-dione (12)

To the reflux solution of **11** (478 mg, 0.84 mmol) in a glacial acetic acid (30 mL), zinc dust (2.10 g) was added portionwise during 1 h and the stirring was continued for another 1 h. At this stage the solid was filtered off and washed with CH_2Cl_2. The filtrate was concentrated *in vacuo*. The residues were purified by silica gel column chromatography (petroleum ether/CH_2Cl_2 = 3/1) to give **12** (463 mg, 0.81 mmol, 96%). $[\alpha]_D^{24}$ = +33.4 (*c* 1.05, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.19 (dd, J = 11.5, 4.3 Hz, 1H), 2.85–2.74 (m, 1H), 2.63 (d, J = 13.1 Hz, 1H), 2.55 (d, J = 13.6 Hz, 1H), 2.42–2.28 (m, 3H), 2.24–2.10 (m, 2H), 2.09–1.97 (m, 1H), 1.26 (s, 3H), 1.19 (s, 3H), 0.92–0.81 (m, 21H), 0.79 (s, 3H), 0.70 (s, 3H), 0.03 (s, 3H), 0.02 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 209.8, 209.7, 79.0, 60.8, 53.2, 52.69, 52.65, 49.1, 48.8, 46.6, 40.1, 39.7, 39.6, 36.9, 36.4, 36.1, 36.0, 33.2, 28.8, 28.3, 28.1, 27.8, 26.0, 24.1, 23.0, 22.7, 18.6, 18.2, 17.7, 16.3, 15.5, 13.9, −3.7, −4.8; HRMS (ESI): *m*/*z* calcd for $C_{36}H_{65}O_3Si$ $[M + H]^+$ 573.4697, found 573.4691.

3β-(*tert*-Butyldimethylsilyloxy)-lanost-7β,11β-diol (13)

To a solution of **12** (700 mg, 1.22 mmol) in anhydrous THF (25 mL) at rt was added $LiAlH_4$ (465 mg, 12.20 mmol). After stirring for 3 h, the reaction mixture was cooled in an ice bath and quenched by the addition of 5% HCl. The resulting solution was extracted with EtOAc. The combined organic phase was washed with brine, dried with Na_2SO_4, filtered and concentrated *in vacuo*. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 25/1) to afford compound **13** (599 mg, 1.04 mmol, 85%). $[\alpha]_D^{24}$ = +47.4 (*c* 0.70, $CHCl_3$); ^{1}H

NMR (500 MHz, $CDCl_3$) δ 4.20 (s, 1H), 3.72–3.55 (m, 1H), 3.19 (dd, $J = 11.4$, 3.6 Hz, 1H), 1.19 (s, 3H), 1.01 (s, 3H), 0.92–0.83 (m, 24H), 0.81 (s, 3H), 0.04 (s, 3H), 0.03 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 79.6, 72.8, 68.7, 52.4, 51.6, 50.4, 48.2, 45.3, 44.6, 42.7, 39.6, 39.5, 37.44, 37.40, 36.5, 36.2, 32.1, 29.0, 28.5, 28.2, 27.9, 26.1, 24.2, 23.0, 22.7, 19.0, 18.3, 18.1, 17.3, 17.1, 16.3, −3.6, −4.8; HRMS (ESI): *m*/*z* calcd for $C_{36}H_{68}O_3SiNa$ $[M + Na]^+$ 599.4830, found 599.4817.

7β-Acetoxy-3β-(*tert*-butyldimethylsilyloxy)-lanost-11-ol (14)

Diol **13** (264 mg, 0.458 mmol) was dissolved in pyridine (20 mL), then DMAP (6 mg, 0.05 mmol) and Ac_2O (130 μL, 1.37 mmol) was sequentially added at 0 °C. The reaction was allowed to stir overnight under argon atmosphere. The reaction was quenched with water and extracted with EtOAc (2 × 40 mL). The combined organic phases were washed thrice with hydrochloric acid (1 M) and brine. The collected organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure, which was purified by silica gel column chromatography (petroleum ether/EtOAc = 50/1) to give **14** (258 mg, 0.42 mmol, 91%). $[\alpha]_D^{24} = +46.4$ (*c* 0.85, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.91 (td, $J = 10.5$, 5.8 Hz, 1H), 4.22 (s, 1H), 3.19 (dd, $J = 11.4$, 4.1 Hz, 1H), 2.25 (dd, $J = 12.4$, 10.2 Hz, 1H), 2.01 (s, 3H), 1.21 (s, 3H), 1.01 (s, 3H), 0.92–0.82 (m, 21H), 0.81 (s, 3H), 0.78 (s, 3H), 0.04 (s, 3H), 0.03 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.7, 79.6, 74.3, 68.6, 52.0, 51.5, 50.6, 48.1, 45.1, 42.7, 40.9, 39.61, 39.57, 37.3, 37.2, 36.7, 36.2, 35.2, 29.0, 28.4, 28.3, 28.1, 27.7, 26.1, 24.2, 23.0, 22.7, 22.1, 19.0, 18.3, 17.8, 17.3, 17.0, 16.3, −3.7, −4.8; HRMS (ESI): *m*/*z* calcd for $C_{38}H_{70}O_4SiNa$ $[M + Na]^+$ 641.4936, found 641.4932.

7β-Acetoxy-3β-(*tert*-butyldimethylsilyloxy)-lanost-9-ene (15)

To a mixture of **14** (80 mg, 0.13 mmol) and Et_3N (36 μL, 0.26 mmol) in CH_2Cl_2 (2 mL) was added methanesulfonyl chloride (MsCl, 20 μL, 0.26 mmol) at 0 °C. After the reaction had been completed, the mixture was diluted with CH_2Cl_2 and washed with saturated aqueous NH_4Cl and brine. The organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The residues were purified by silica gel column chromatography (petroleum ether/EtOAc = 20/1) to give **15** (80 mg, 0.11 mmol, 89%). $[\alpha]_D^{24} = +34.6$ (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.33 (d, $J = 6.2$ Hz, 1H), 4.92 (td, $J = 11.0$, 5.2 Hz, 1H), 3.18 (dd, $J = 10.8$, 4.9 Hz, 1H), 2.43 (d, $J = 11.0$ Hz, 1H), 2.04 (s, 3H), 1.08 (s, 3H), 0.90–0.84 (m, 21H), 0.77 (s, 3H), 0.76 (s, 3H), 0.67 (s, 3H), 0.04 (s, 3H), 0.03 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.5, 145.8, 118.0, 79.3, 77.2, 74.5, 50.4, 48.2, 46.7, 46.4, 45.0, 39.6, 39.0, 36.9, 36.6, 36.3, 36.2, 35.8, 28.61, 28.57, 28.3, 28.2, 27.9, 26.1, 24.2, 23.0, 22.7, 22.1, 22.0, 18.6, 18.5, 18.3, 16.1, 14.5, −3.7, −4.8.

7β-Acetoxylanost-9-ene (16)

To a solution of compound **15** (157 mg, 0.26 mmol) in THF (3.0 mL) in a TEFLON tube was added a solution of 70% HF·pyridine (0.88 mL). The reaction mixture was stirred for 6 h at 40 °C, and quenched with saturated $NaHCO_3$ solution. The resultant mixture was extracted with EtOAc. The combined organic layers were washed with saturated aqueous $NaHCO_3$, dried over Na_2SO_4, filtered and concentrated. The crude product was purified by silica gel column chromatography (petroleum ether/EtOAc = 5/1) to give **16** (112 mg, 0.23 mmol, 88%). $[\alpha]_D^{24} = +48.8$ (*c* 0.55, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.34 (d, $J = 6.1$ Hz, 1H), 4.92 (td, $J = 11.0$, 5.2 Hz, 1H), 3.31–3.14 (m, 1H), 2.43 (d, $J = 10.6$ Hz, 1H), 2.04 (s, 3H), 1.08 (s, 3H), 0.99 (s, 3H), 0.90–0.83 (m, 9H), 0.81 (s, 3H), 0.77 (s, 3H), 0.67 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.5, 145.5, 118.3, 78.8, 77.2, 74.4, 50.4, 48.3, 46.7, 46.4, 45.0, 39.6, 39.1, 36.9, 36.6, 36.3, 36.2, 35.8, 28.6, 28.20, 28.15, 27.8, 27.7, 24.2, 23.0, 22.7, 22.1, 22.0, 18.6, 18.5, 15.7, 14.5; HRMS (ESI): *m*/*z* calcd for $C_{32}H_{54}O_3Na$ $[M + Na]^+$ 509.3965, found 509.3965.

7β-Acetoxy-24,25-dihydrolanosterol (17)

To a solution of olefin **16** (65 mg, 0.13 mmol) in MeOH (12 mL) was added 10% Pd/C (100 mg) and AcOH (600 μL). The reaction vessel was evacuated and backfilled with hydrogen (130 atm). The mixture was kept at 120 °C for 72 h, then filtered through a thin plug of Celite. The filtrate was washed with EtOAc (2 × 50 mL) and concentrated *in vacuo*. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 5/1) to afford **17** (62 mg, 0.13 mmol, 95%). $[\alpha]_D^{24} = +37.7$ (*c* 0.90, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.85 (td, $J = 10.6$, 5.3 Hz, 1H), 3.21 (dd, $J = 11.4$, 3.2 Hz, 1H), 2.00 (s, 3H), 1.96–1.77 (m, 3H), 0.96 (s, 3H), 0.94 (s, 3H), 0.88–0.84 (m, 9H), 0.83 (s, 3H), 0.79 (s, 3H), 0.78 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.6, 78.9, 77.2, 74.6, 51.6, 50.1, 47.3, 46.9, 45.9, 43.0, 39.6, 38.9, 37.4, 36.7, 36.2, 35.5, 31.9, 28.5, 28.24, 28.16, 28.1, 27.7, 24.2, 23.0, 22.7, 22.1, 20.3, 18.9, 16.7, 15.6, 14.5, 13.9; HRMS (ESI): *m*/*z* calcd for $C_{32}H_{56}O_3Na$ $[M + Na]^+$ 511.4122, found 511.4123.

3β-Benzoyloxylanost-7β-ol (18)

To a solution of **17** (1.30 g, 3.03 mmol) in pyridine (20 mL) was added DMAP (37 mg, 0.30 mmol) and BzCl (528 μL, 4.55 mmol) at 0 °C. The reaction was stirred for 6 h at room temperature and quenched with water. After removal of solvent, the residue was dissolved in CH_2Cl_2 and washed with 0.1 M HCl, saturated aqueous $NaHCO_3$. The organic phase was dried over anhydrous Na_2SO_4, filtered and concentrated. The resulting residue was dissolved in 65 mL of $CH_3OH/CHCl_3$ (v/v = 1.6/1) followed by dropwise addition of acetyl chloride (4.80 mL) at 0 °C. The reaction mixture was stirred for 24 h at 40 °C, and then quenched with Et_3N. The volatile was evaporated *in vacuo*. The resulting residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 15/1) to afford **18** (1.04 g, 1.89 mmol, 62%) with the recovery of acetate (363 mg, 0.61 mmol). $[\alpha]_D^{24} = +35.7$ (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, $J = 7.7$ Hz, 2H), 7.55 (t, $J = 7.3$ Hz, 1H), 7.44 (t, $J = 7.6$ Hz, 2H), 4.72 (dd, $J = 11.4$, 4.3 Hz, 1H), 3.64 (td, $J = 10.0$, 4.9 Hz, 1H), 1.05 (s, 3H), 1.00 (s, 3H), 0.94 (s, 3H), 0.91 (s, 3H), 0.79 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.4, 132.9, 131.0, 129.6, 128.4, 81.5, 77.2, 73.1, 52.1, 49.8, 47.4, 46.7, 46.4, 46.1, 39.6, 38.2, 37.2, 36.8, 36.7, 36.6, 36.2, 31.9, 31.6, 28.7, 28.3, 28.1, 24.2, 22.9, 22.7, 20.3, 18.9, 17.0, 16.8, 14.5, 14.1; HRMS (ESI): *m*/*z* calcd for $C_{37}H_{58}O_3Na$ $[M + Na]^+$ 573.4278, found 573.4283.

Lanost-7β-*O*-methylsulfony-3β-yl benzoate (19)

To a solution of **18** (100 mg, 0.18 mmol) in CH_2Cl_2 (2.0 mL) was added MsCl (42 μL, 0.55 mmol) and Et_3N (126 μL, 0.91 mmol) dropwise at 0 °C. The reaction mixture was stirred for 5 h at room temperature, and then quenched with MeOH. The volatile was evaporated *in vacuo*. The resulting residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 15/1) to afford **19** (99 mg, 0.16 mmol, 87%). $[\alpha]_D^{24}$ = +33.4 (*c* 0.55, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.3 Hz, 2H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.44 (t, *J* = 7.7 Hz, 2H), 4.79 (td, *J* = 10.6, 5.3 Hz, 1H), 4.71 (dd, *J* = 11.6, 4.3 Hz, 1H), 3.01 (s, 3H), 2.41–2.26 (m, 1H), 1.05 (s, 3H), 1.02 (s, 3H), 0.95 (s, 3H), 0.94 (s, 3H), 0.90–0.84 (m, 9H), 0.79 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.3, 133.0, 130.9, 129.7, 128.5, 83.2, 81.2, 51.9, 50.0, 47.1, 47.0, 46.1, 44.0, 40.1, 39.6, 38.2, 37.0, 36.7, 36.5, 36.2, 35.4, 31.6, 29.6, 28.5, 28.3, 28.1, 24.2, 24.1, 23.0, 22.7, 20.4, 19.0, 17.0, 16.5, 14.5, 14.0.

3β-Benzoyloxylanost-7-ene (21)

Method A. 19 (50 mg, 0.08 mmol) was dissolved in acetic acid (2.0 mL) and then added NaOAc (46 mg, 0.56 mmol). The reaction mixture was stirred for 0.5 h at 120 °C. After removal of solvent, the residue was dissolved in CH_2Cl_2 and washed with brine, dried over anhydrous Na_2SO_4, filtered and concentrated for flash column chromatography (petroleum ether/CH_2Cl_2 = 3/1) to afford a mixture of **20** and **21** (41 mg, 0.07 mmol, 87%) at the ratio of **20**/**21** = 1/12.5.

Method B. To a solution of **18** (1.50 g, 2.73 mmol) in CH_2Cl_2 (50 mL) was added pyridine (2.64 mL, 32.8 mmol) at −10 °C followed by Tf_2O (1.15 mL, 6.81 mmol). The reaction mixture was stirred for 5 h at −10 °C, and then quenched with H_2O. The solvent was evaporated *in vacuo*. The resulting residue was purified by column chromatography (petroleum ether/CH_2Cl_2 = 3/1) to afford a mixture of **20** and **21** (1.38 g, 2.62 mmol, 96%) at the ratio of **20**/**21** = 1/20. $[\alpha]_D^{24}$ = +41.3 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (d, *J* = 7.3 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.44 (t, *J* = 7.7 Hz, 2H), 5.22 (d, *J* = 5.3 Hz, 1H), 4.77 (dd, *J* = 11.4, 4.3 Hz, 1H), 1.13 (s, 3H), 0.99 (s, 3H), 0.95 (s, 3H), 0.94 (s, 3H), 0.91–0.85 (m, 9H), 0.66 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.3, 145.1, 132.7, 131.0, 129.5, 128.3, 116.4, 81.8, 52.0, 50.8, 50.4, 47.1, 44.3, 39.5, 37.9, 37.7, 36.5, 36.4, 35.5, 32.2, 32.1, 28.3, 28.0, 27.6, 24.8, 24.10, 24.08, 22.8, 22.8, 22.5, 20.1, 19.0, 16.9, 16.1, 14.2.

Lanost-7-en-3β-ol (5)

To a solution of **21** (700 mg, 1.31 mmol) in THF (15 mL) was added $LiAlH_4$ (250 mg, 6.57 mmol) at 0 °C. The reaction was stirred for 4 h at room temperature and quenched with 0.1 M HCl. The mixture was extracted with ethyl acetate. The organic phase was washed with 0.1 M HCl, brine, dried over anhydrous Na_2SO_4, filtered and concentrated. The residue was applied to silica gel column chromatography (petroleum ether/EtOAc = 15/1) to afford **5** (501 mg, 1.17 mmol, 89%). $[\alpha]_D^{24}$ = +3.8 (*c* 0.70, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.21 (d, *J* = 4.3 Hz, 1H), 3.25 (dd, *J* = 11.0, 4.5 Hz, 1H), 0.99 (s, 3H), 0.97 (s, 3H), 0.91–0.84 (m, 15H), 0.64 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.1, 116.8, 79.5, 52.1, 51.0, 50.4, 47.4, 44.5, 39.7, 38.8, 38.3, 36.7, 36.6, 35.8, 32.3, 32.2, 28.4, 28.2, 27.8, 27.6, 25.0, 24.3, 23.1, 23.0, 22.7, 20.2, 19.1, 16.2, 15.6, 14.3; HRMS (ESI): *m*/*z* calcd for $C_{30}H_{52}ONa$ $[M + Na]^+$ 451.3910, found 451.3908.

***p*-Tolyl 4-*O*-(2-naphthylmethyl)-1-thio-β-D-xylopyranoside (23)**

Alcohol **22** (1.69 g, 5.71 mmol) was dissolved in *N*,*N*-dimethylformamide (50 mL) followed by addition of NaH (457 mg, 11.42 mmol) at 0 °C. After stirring for 20 min under argon atmosphere, NapBr (1.55 mL, 6.85 mmol) was added to the reaction mixture. With stirring for another 6 h, the reaction was quenched by methanol and poured into water. The mixture was extracted with CH_2Cl_2. The organic phase was collected and washed with HCl (1 M), saturated $NaHCO_3$, dried over Na_2SO_4, filtered and concentrated *in vacuo*. The residue was dissolved in 50 mL of CH_2Cl_2/MeOH (v/v = 1/1), and then CSA (1.69 g, 5.71 mmol) was added. The reaction was stirred at room temperature for 5 h, then quenched by Et_3N and concentrated. The residue was purified by silica gel column (petroleum ether/EtOAc = 2/1) to afford **23** (2.17 g, 5.48 mmol, 96% for two steps). $[\alpha]_D^{24}$ = −61.8 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87–7.72 (m, 4H), 7.52–7.35 (m, 5H), 7.11 (d, *J* = 7.8 Hz, 2H), 4.85 (d, *J* = 11.9 Hz, 1H), 4.79 (d, *J* = 11.9 Hz, 1H), 4.47 (d, *J* = 9.0 Hz, 1H), 4.09 (dd, *J* = 11.5, 4.8 Hz, 1H), 3.69 (t, *J* = 8.4 Hz, 1H), 3.56–3.45 (m, 1H), 3.35 (t, *J* = 8.7 Hz, 1H), 3.29 (t, *J* = 10.7 Hz, 1H), 2.33 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.6, 135.5, 133.5, 133.3, 133.2, 123.0, 128.6, 128.0, 127.8, 126.9, 126.4, 126.2, 125.8, 89.0, 76.9, 76.7, 73.3, 72.0, 67.3, 21.3; HRMS (ESI): *m*/*z* calcd for $C_{23}H_{28}O_4NS$ $[M + NH_4]^+$ 414.1734, found 414.1727.

***p*-Tolyl 3-*O*-benzoyl-4-*O*-(2-naphthylmethyl)-1-thio-β-D-xylopyranoside (24)**

Diol **23** (1.88 g, 4.74 mmol) and dibutyltin oxide (1.30 g, 5.22 mmol) was dissolved in anhydrous toluene (45 mL). The resulting mixture was refluxed for 2 h with a Dean–Stark trap to remove the formed water during the reaction. At this stage the reaction was cooled to room temperature followed by addition of benzoyl chloride (605 μL, 5.22 mmol) dropwise. After the mixture was stirred for another 5 h, the volatile was removed *in vacuo*. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 8/1) to afford **24** (1.42 g, 2.84 mmol, 60%). $[\alpha]_D^{24}$ = −90.9 (*c* 0.75, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.11 (d, *J* = 7.5 Hz, 2H), 7.84–7.76 (m, 1H), 7.76–7.67 (m, 3H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.52–7.33 (m, 7H), 7.13 (d, *J* = 8.0 Hz, 2H), 5.40 (t, *J* = 6.2 Hz, 1H), 4.99 (d, *J* = 5.5 Hz, 1H), 4.84 (d, *J* = 12.1 Hz, 1H), 4.80 (d, *J* = 12.1 Hz, 1H), 4.40 (dd, *J* = 12.2, 3.3 Hz, 1H), 3.77 (t, *J* = 5.8 Hz, 1H), 3.75–3.70 (m, 1H), 3.65 (dd, *J* = 12.2, 6.2 Hz, 1H), 2.34 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.0, 138.3, 134.7, 133.5, 133.3, 133.2, 133.0, 130.2, 130.0, 129.6, 128.59, 128.56, 128.0, 127.8, 127.0, 126.4, 126.2, 125.8, 89.5, 73.7, 72.5, 70.4, 63.5, 21.3; HRMS (ESI): *m*/*z* calcd for $C_{30}H_{28}O_5SNa$ $[M + Na]^+$ 523.1550, found 523.1554.

***p*-Tolyl 2-*O*-[2-(azidomethyl)benzoyl]-3-*O*-benzoyl-4-*O*-(2-naphthyl-methyl)-1-thio-β-D-xylopyranoside (6)**

To a solution of **24** (200 mg, 0.40 mmol) in dry CH_2Cl_2 (5 mL) were added AzmbOH (106 mg, 0.60 mmol), EDCI (153 mg, 0.80

mmol), and DMAP (97 mg, 0.80 mmol) under argon atmosphere. The mixture was stirred for 12 h, and diluted with CH_2Cl_2 followed by washing with 1 M HCl, saturated aqueous $NaHCO_3$, and brine. The organic phase was dried over Na_2SO_4, filtered and concentrated. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 7/1) to give **6** (239 mg, 0.36 mmol, 91%). $[\alpha]_D^{24}$ = +33.4 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98 (dd, *J* = 8.2, 1.0 Hz, 2H), 7.92 (dd, *J* = 7.8, 1.0 Hz, 1H), 7.79–7.71 (m, 1H), 7.69–7.59 (m, 3H), 7.59–7.53 (m, 1H), 7.51–7.33 (m, 8H), 7.30 (dd, *J* = 8.4, 1.5 Hz, 1H), 7.28–7.22 (m, 1H), 7.11 (d, *J* = 8.0 Hz, 2H), 5.62 (t, *J* = 8.1 Hz, 1H), 5.27 (t, *J* = 8.3 Hz, 1H), 4.95 (d, *J* = 8.4 Hz, 1H), 4.78 (d, *J* = 12.2 Hz, 1H), 4.72 (d, *J* = 12.2 Hz, 1H), 4.64 (d, *J* = 14.8 Hz, 1H), 4.54 (d, *J* = 14.8 Hz, 1H), 4.32 (dd, *J* = 11.9, 4.7 Hz, 1H), 3.90–3.76 (m, 1H), 3.58 (dd, *J* = 11.9, 8.9 Hz, 1H), 2.33 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 165.7, 165.3, 138.6, 137.6, 135.0, 133.5, 133.4, 133.21, 133.15, 133.0, 131.3, 130.1, 130.0, 129.41, 129.35, 128.7, 128.6, 128.4, 128.20, 128.15, 128.0, 127.8, 126.9, 126.3, 126.2, 125.8, 86.9, 74.4, 74.1, 73.0, 70.7, 66.6, 52.8, 21.3; HRMS (ESI): *m*/*z* calcd for $C_{38}H_{33}O_6N_3SNa$ $[M + Na]^+$ 682.1988, found 682.2000.

Lanost-7-en-3β-yl 2-*O*-[2-(azidomethyl)benzoyl]-3-*O*-benzoyl-4-*O*-(2-naphthylmethyl)-β-D-xylopyranoside (25)

A solution of alcohol **5** (24 mg, 0.057 mmol) and thioglycoside 6 (50 mg, 0.074 mmol) in dry CH_2Cl_2 (2 mL) was stirred vigorously in the presence of activated 4 Å molecular sieves (200 mg) for 20 min. The mixture was cooled to 0 °C, then NIS (26 mg, 0.114 mmol) and TMSOTf (1 μL, 0.0057 mmol) were added. After stirring for 2 h, the reaction mixture was quenched with Et_3N, and the solid was filtered off. The filtrate was washed with saturated aqueous $Na_2S_2O_3$ and brine. The organic phase was dried over Na_2SO_4, filtered and concentrated. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 17/1) to give **25** (51 mg, 0.052 mmol, 91%). $[\alpha]_D^{24}$ = +45.6 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, *J* = 7.4 Hz, 3H), 7.77–7.71 (m, 1H), 7.70–7.59 (m, 3H), 7.53 (t, *J* = 7.4 Hz, 1H), 7.50–7.39 (m, 4H), 7.36 (t, *J* = 7.8 Hz, 2H), 7.32–7.27 (m, 2H), 5.62 (t, *J* = 8.8 Hz, 1H), 5.30 (dd, *J* = 9.0, 7.2 Hz, 1H), 5.13 (d, *J* = 5.3 Hz, 1H), 4.77 (d, *J* = 12.3 Hz, 1H), 4.74–4.68 (m, 2H), 4.62 (s, 2H), 4.14 (dd, *J* = 11.9, 4.9 Hz, 1H), 3.90–3.80 (m, 1H), 3.50 (dd, *J* = 11.8, 9.5 Hz, 1H), 3.12 (dd, *J* = 11.7, 3.5 Hz, 1H), 0.94 (s, 3H), 0.90–0.84 (m, 9H), 0.83 (s, 3H), 0.76 (s, 3H), 0.72 (s, 3H), 0.61 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 165.9, 165.1, 145.0, 137.9, 135.1, 133.4, 133.23, 133.17, 133.0, 131.3, 130.0, 129.6, 129.2, 128.50, 128.45, 128.0, 127.9, 127.8, 127.0, 126.3, 126.2, 125.9, 116.7, 103.1, 90.2, 75.0, 73.7, 73.1, 72.2, 63.4, 52.9, 52.1, 51.0, 50.6, 47.3, 44.5, 39.7, 38.8, 38.2, 36.7, 36.6, 35.4, 32.3, 32.2, 28.15, 28.13, 27.7, 26.2, 24.9, 24.3, 23.0, 22.9, 22.7, 20.2, 19.1, 16.4, 16.2, 14.2; HRMS (ESI): *m*/*z* calcd for $C_{61}H_{77}O_7N_3Na$ $[M + Na]^+$ 986.5659, found 986.5671.

Lanost-7-en-3β-yl 3-*O*-benzoyl-4-*O*-(2-naphthylmethyl)-β-D-xylopyranoside (3)

To a solution of **25** (400 mg, 0.41 mmol, 1 equiv.) in THF (10 mL) were added Bu_3P (815 μL, 3.26 mmol, 8 equiv.) and water (0.40 mL) under argon atmosphere. The reaction mixture was stirred for 1 h at 50 °C, when TLC monitoring indicated that the reactant was completely consumed. The reaction mixture was diluted with EtOAc, washed with saturated aqueous $NaHCO_3$ and brine. The organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/CH_2Cl_2/EtOAc = 20/5/1) to give **3** (300 mg, 0.38 mmol, 92%). $[\alpha]_D^{24}$ = −29.1 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, *J* = 7.4 Hz, 2H), 7.82–7.75 (m, 1H), 7.75–7.66 (m, 3H), 7.57 (t, *J* = 7.4 Hz, 1H), 7.50–7.34 (m, 5H), 5.37 (t, *J* = 7.0 Hz, 1H), 5.18 (d, *J* = 2.6 Hz, 1H), 4.81 (d, *J* = 12.2 Hz, 1H), 4.78 (d, *J* = 12.2 Hz, 1H), 4.60 (d, *J* = 5.2 Hz, 1H), 4.14 (dd, *J* = 12.1, 3.8 Hz, 1H), 3.78–3.71 (m, 1H), 3.71–3.65 (m, 1H), 3.51 (dd, *J* = 12.0, 7.2 Hz, 1H), 3.18 (dd, *J* = 11.7, 3.4 Hz, 1H), 2.87 (d, *J* = 6.3 Hz, 1H), 0.97 (s, 3H), 0.96 (s, 3H), 0.91–0.84 (m, 15H), 0.64 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.1, 145.1, 135.0, 133.31, 133.26, 133.2, 130.1, 129.9, 128.5, 128.4, 128.0, 127.8, 127.0, 126.3, 126.2, 125.9, 116.7, 104.7, 90.0, 74.1, 73.1, 72.6, 71.3, 61.7, 52.1, 51.0, 50.6, 47.3, 44.5, 39.7, 39.0, 38.3, 36.7, 36.6, 35.4, 32.3, 32.2, 28.5, 28.2, 27.8, 26.3, 25.0, 24.3, 23.0, 22.9, 22.7, 20.2, 19.1, 16.6, 16.2, 14.3; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{72}O_6Na$ $[M + Na]^+$ 827.5221, found 827.5230.

p-Tolyl 3-*O*-acetyl-2,4-di-*O*-benzyl-1-thio-β-D-xylopyranoside (27)

26 (100 mg, 0.39 mmol) was allowed to react with acetic anhydride (41 μL, 0.43 mmol) in dry acetonitrile (1.5 mL) at 40 °C for 12 h in the presence of tetrabutylammonium acetate (35 mg, 0.12 mmol). The solution was concentrated *in vacuo* and directly purified by flash column chromatography (petroleum ether/EtOAc = 1.5/1). The resulting residue was dissolved in pyridine (2 mL) and then benzoyl chloride (111 μL, 0.93 mmol) and DMAP (3 mg, 0.023 mmol) were added. After the reaction went to completion, the mixture was concentrated *in vacuo*. The residue was diluted with CH_2Cl_2 and washed with 1 M HCl, saturated aqueous solution of $NaHCO_3$ and brine. The combined organic phase dried over Na_2SO_4, filtered and concentrated. The obtained residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 8/1) to afford **27** (116 mg, 0.23 mmol, 59% for two steps). $[\alpha]_D^{24}$ = −52.1 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 (d, *J* = 7.4 Hz, 2H), 8.00 (d, *J* = 7.5 Hz, 2H), 7.62–7.53 (m, 2H), 7.47–7.33 (m, 6H), 7.12 (d, *J* = 7.9 Hz, 2H), 5.54 (t, *J* = 7.7 Hz, 1H), 5.26 (t, *J* = 7.6 Hz, 1H), 5.21–5.13 (m, 1H), 5.01 (d, *J* = 7.6 Hz, 1H), 4.54 (dd, *J* = 11.9, 4.6 Hz, 1H), 3.64 (dd, *J* = 11.9, 8.0 Hz, 1H), 2.34 (s, 3H), 1.97 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 169.9, 165.6, 165.2, 138.7, 133.62, 133.56, 133.54, 130.1, 130.0, 129.9, 129.4, 129.3, 128.7, 128.65, 128.60, 86.9, 71.4, 70.3, 69.2, 65.0, 21.3, 20.8; HRMS (ESI): *m*/*z* calcd for $C_{28}H_{30}O_7NS$ $[M + NH_4]^+$ 524.1737, found 524.1723.

p-Tolyl 2,4-di-*O*-benzoyl-1-thio-β-D-xylopyranoside (7a)

To a solution of **27** (2.86 g, 5.65 mmol) in 50 mL of MeOH/CH_2Cl_2 (v/v = 1/2) was added acetyl chloride (2.0 mL) dropwise at 0 °C. The reaction mixture was stirred for 24 h, and then quenched with Et_3N. The volatile was removed *in vacuo*. The resulting residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 6/1) to afford **7a** (2.58 g, 5.37 mmol, 95%). $[\alpha]_D^{24}$ = −59.3 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$)

δ 8.06 (d, J = 8.1 Hz, 2H), 8.02 (d, J = 8.1 Hz, 2H), 7.65–7.50 (m, 2H), 7.49–7.31 (m, 6H), 7.11 (d, J = 7.8 Hz, 2H), 5.19–5.06 (m, 2H), 5.00 (d, J = 7.5 Hz, 1H), 4.48 (dd, J = 11.9, 4.4 Hz, 1H), 4.14 (t, J = 7.5 Hz, 1H), 3.61 (dd, J = 11.8, 8.0 Hz, 1H), 2.34 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.3, 138.6, 133.63, 133.58, 133.52, 130.2, 130.0, 129.9, 129.57, 129.55, 128.9, 128.61, 128.59, 86.4, 73.1, 72.4, 71.7, 64.6, 21.4; HRMS (ESI): m/z calcd for $C_{26}H_{25}O_6S$ $[M + H]^+$ 465.1366, found 465.1353.

2,4,6-Tri-*O*-benzoyl-3-*O*-methyl-α-D-glucopyranosyl trichloroacetimidate (8)

To a solution of hemiacetal **28** (2.90 g, 5.73 mmol) in CH_2Cl_2 (50 mL) were added Cl_3CCN (5.75 mL, 57.3 mmol) and DBU (0.17 mL, 1.15 mmol). The resulting mixture was stirred at room temperature for 6 h followed by concentration *in vacuo*. The residue was purified by silica gel flash column chromatography (petroleum ether/EtOAc = 7/1) to give **8** (3.53 g, 5.44 mmol, 95%). $[\alpha]_D^{24}$ = +81.5 (c 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.60 (s, 1H), 8.16–7.95 (m, 6H), 7.67–7.50 (m, 3H), 7.51–7.34 (m, 6H), 6.71 (d, J = 3.7 Hz, 1H), 5.58 (t, J = 9.8 Hz, 1H), 5.43 (dd, J = 9.8, 3.8 Hz, 1H), 4.59 (dd, J = 12.2, 2.4 Hz, 1H), 4.44–4.54 (m, 1H), 4.39 (dd, J = 12.2, 5.2 Hz, 1H), 4.18 (t, J = 9.6 Hz, 1H), 3.50 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.1, 165.3, 165.1, 160.4, 133.5, 133.5, 133.1, 129.9, 129.8, 129.7, 129.6, 129.2, 129.2, 128.5, 128.5, 128.3, 93.4, 79.0, 72.10, 70.6, 70.0, 62.7, 60.8; HRMS (ESI): m/z calcd for $C_{30}H_{26}O_9NCl_3Na$ $[M + Na]^+$ 672.0565, found 672.0555.

p-Tolyl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-1-thio-β-D-glucopyranoside (29)

A solution of compound **7a** (38 mg, 0.082 mmol) and **8** (80 mg, 0.12 mmol) in anhydrous CH_2Cl_2 (2 mL) was stirred vigorously in the presence of activated 4 Å molecular sieves (2 g) for 20 min. The mixture was cooled to 0 °C and TMSOTf (1.5 μL, 0.0082 mmol) was added. After 1 h, the reaction mixture was quenched with Et_3N, and the solid was filtered off. The filtrate was concentrated *in vacuo* and the resulting residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 7/1) to afford **29** (28 mg, 0.046 mmol, 56%). $[\alpha]_D^{24}$ = +9.4 (c 1.25, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15–8.08 (m, 2H), 8.03 (m, 4H), 7.65–7.54 (m, 3H), 7.51–7.40 (m, 6H), 7.35 (d, J = 8.1 Hz, 2H), 6.88 (d, J = 8.0 Hz, 2H), 5.41 (t, J = 9.6 Hz, 1H), 5.28 (t, J = 9.4 Hz, 1H), 4.84 (d, J = 10.0 Hz, 1H), 4.64 (dd, J = 12.1, 2.7 Hz, 1H), 4.40 (dd, J = 12.1, 6.3 Hz, 1H), 4.05–3.96 (m, 1H), 3.86 (t, J = 9.1 Hz, 1H), 3.38 (s, 3H), 2.24 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.3, 165.2, 165.1, 138.4, 133.6, 133.5, 133.4, 133.2, 130.0, 129.97, 129.96, 129.8, 129.7, 129.4, 128.7, 128.6, 128.50, 128.48, 86.6, 83.5, 76.3, 71.9, 70.6, 63.5, 60.1, 21.2; HRMS (ESI): m/z calcd for $C_{35}H_{36}O_8NS$ $[M + NH_4]^+$ 630.2156, found 630.2149.

4-Methoxyphenyl 3-*O*-acetyl-2,4-di-*O*-benzoyl-β-D-xylopyranoside (31)

Following the procedure for the preparation of compound **27**, **30** (1.35 mg, 5.27 mmol) was converted into **31** (1.6 mg, 3.16 mmol, 60%) over two steps by purification with silica gel column (petroleum ether/EtOAc = 6/1). $[\alpha]_D^{24}$ = −34.2 (c 0.90, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 (d, J = 7.7 Hz, 4H), 7.63–7.51 (m, 2H), 7.48–7.34 (m, 4H), 6.96 (d, J = 9.0 Hz, 2H), 6.80 (d, J = 9.0 Hz, 2H), 5.60 (t, J = 7.6 Hz, 1H), 5.47 (dd, J = 7.6, 5.8 Hz, 1H), 5.31–5.20 (m, 2H), 4.45 (dd, J = 12.2, 4.4 Hz, 1H), 3.75 (s, 3H), 3.70 (dd, J = 12.2, 7.3 Hz, 1H), 2.02 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.0, 165.6, 165.3, 155.7, 150.8, 133.7, 133.6, 130.04, 130.02, 129.31, 129.29, 128.7, 128.6, 118.8, 114.7, 99.9, 70.5, 70.3, 69.3, 61.9, 55.8, 20.9; HRMS (ESI): m/z calcd for $C_{28}H_{26}O_9Na$ $[M + Na]^+$ 529.1469, found 529.1458.

4-Methoxyphenyl 2,4-di-*O*-benzoyl-β-D-xylopyranoside (7b)

Following the procedure for the preparation of **7a**, **7b** (85 mg, 0.18 mmol, 93%), purified by silica gel column chromatography (CH_2Cl_2/EtOAc = 10/1), was prepared from compound **31** (100 mg, 0.20 mmol). $[\alpha]_D^{24}$ = −49.0 (c 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, J = 8.0 Hz, 2H), δ 8.03 (d, J = 8.0 Hz, 2H), 7.62–7.50 (m, 2H), 7.44–7.30 (m, 4H), 7.02 (d, J = 8.9 Hz, 2H), 6.83 (d, J = 8.9 Hz, 2H), 5.41 (d, J = 4.1 Hz, 1H), 5.34 (t, J = 4.9 Hz, 1H), 5.24–5.15 (m, 1H), 4.45 (dd, J = 12.8, 3.4 Hz, 1H), 4.25 (t, J = 5.6 Hz, 1H), 3.81 (dd, J = 12.8, 5.0 Hz, 1H), 3.77 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 166.0, 155.8, 150.4, 133.6, 133.5, 130.1, 130.0, 129.7, 129.4, 128.5, 118.6, 114.8, 99.0, 71.5, 71.1, 69.4, 60.4, 55.8; HRMS (ESI): m/z calcd for $C_{26}H_{24}O_8Na$ $[M + Na]^+$ 487.1363, found 487.1355.

4,6-Di-*O*-benzoyl-3-*O*-methyl-α-D-glucopyranose-1,2-diyl (4-methoxyphenyl 2,4-di-benzoyl β-D-xylopyranoside)-3-yl orthobenzoate (32)

Following the procedure for the preparation of compound **29**, the coupling of **7b** (38 mg, 0.083 mmol) and **8** (70 mg, 0.108 mmol) in CH_2Cl_2 in the presence of TMSOTf (1.5 μL, 0.0083 mmol) furnished **32** (28 mg, 0.029 mmol, 35%) after purification by silica gel column chromatography (toluene/EtOAc = 20/1). $[\alpha]_D^{24}$ = −5.3 (c 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 (d, J = 7.6 Hz, 2H), 7.94 (d, J = 7.6 Hz, 2H), 7.85 (d, J = 6.9 Hz, 2H), 7.83 (d, J = 6.9 Hz, 2H), 7.69 (d, J = 7.4 Hz, 2H), 7.58 (t, J = 7.5 Hz, 1H), 7.54 (t, J = 7.5 Hz, 1H), 7.48 (t, J = 7.4 Hz, 1H), 7.42 (t, J = 7.5 Hz, 3H), 7.38–7.28 (m, 7H), 7.17 (t, J = 7.6 Hz, 2H), 6.95 (d, J = 9.0 Hz, 2H), 6.78 (d, J = 9.0 Hz, 2H), 6.04 (d, J = 5.2 Hz, 1H), 5.37 (t, J = 4.6 Hz, 1H), 5.28 (m, 1H), 5.21–5.15 (m, 1H), 5.12 (d, J = 8.9 Hz, 1H), 4.91–4.84 (m, 1H), 4.39 (dd, J = 12.4, 3.3 Hz, 1H), 4.28–4.17 (m, 2H), 4.11 (t, J = 5.3 Hz, 1H), 3.86–3.78 (m, 1H), 3.75 (s, 3H), 3.68 (dd, J = 12.5, 5.2 Hz, 1H), 3.59 (s, 3H), 3.55 (s, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.1, 165.5, 165.4, 165.2, 155.4, 150.8, 135.5, 133.5, 133.4, 133.3, 133.0, 130.0, 129.90, 129.87, 129.81, 129.78, 129.76, 129.51, 129.49, 128.5, 128.4, 128.34, 128.29, 126.7, 122.0, 118.4, 114.7, 98.7, 97.9, 77.1, 73.3, 70.8, 70.5, 69.4, 68.5, 67.4, 64.5, 60.6, 58.6, 55.8; HRMS (ESI): m/z calcd for $C_{54}H_{52}O_{16}N$ $[M + NH_4]^+$ 970.3281, found 970.3283.

4-Methoxyphenyl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-α-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranoside (33α) and 4-methoxyphenyl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranoside (33β)

According to the protocol for the synthesis of **29**, TBSOTf (6.0 μL, 0.025 mmol)-catalyzed glycosylation of **7b** (38 mg, 0.083 mmol) and **8** (70 mg, 0.108 mmol) in anhydrous CH_2Cl_2 (2 mL) to afford

33α (18 mg, 0.019 mmol, 23%) and **33β** (31 mg, 0.032 mmol, 39%) with the purification of silica gel column chromatography (toluene/EtOAc = 30/1) **33α**: $[\alpha]_D^{24}$ = +66.8 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, J = 7.3 Hz, 2H), 7.99 (d, J = 7.2 Hz, 2H), 7.95 (d, J = 7.3 Hz, 2H), 7.89 (d, J = 7.2 Hz, 2H), 7.79 (d, J = 7.3 Hz, 2H), 7.63–7.42 (m, 7H), 7.39 (s, 2H), 7.35–7.27 (m, 6H), 7.00 (d, J = 9.1 Hz, 2H), 6.81 (d, J = 9.1 Hz, 2H), 5.64 (d, J = 3.7 Hz, 1H), 5.60–5.54 (m, 1H), 5.46 (t, J = 9.7 Hz, 1H), 5.27 (d, J = 4.9 Hz, 1H), 5.19–5.04 (m, 2H), 4.47–4.28 (m, 4H), 4.07 (t, J = 9.7 Hz, 1H), 3.91 (dd, J = 12.2, 4.0 Hz, 1H), 3.77 (s, 3H), 3.56 (dd, J = 12.3, 6.2 Hz, 1H), 3.44 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 165.4, 165.2, 165.0, 155.6, 150.8, 133.8, 133.52, 133.49, 133.1, 129.98, 129.93, 129.86, 129.85, 129.5, 129.22, 129.21, 129.0, 128.7, 128.6, 128.53, 128.46, 128.4, 118.5, 114.8, 99.3, 96.9, 78.8, 73.9, 72.8, 70.7, 70.6, 70.5, 68.7, 62.5, 60.9, 60.8, 55.8; HRMS (ESI): *m*/*z* calcd for $C_{54}H_{52}O_{16}N$ $[M + NH_4]^+$ 970.3281, found 970.3261. **33β**: $[\alpha]_D^{24}$ = −35.6 (*c* 0.75, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, J = 7.6 Hz, 2H), 8.00 (d, J = 7.5 Hz, 2H), 7.95–7.89 (m, 6H), 7.60–7.40 (m, 6H), 7.36–7.22 (m, 7H), 7.12 (t, J = 7.7 Hz, 2H), 6.73 (d, J = 9.1 Hz, 2H), 6.67 (d, J = 9.1 Hz, 2H), 5.52–5.42 (m, 2H), 5.32 (s, 1H), 5.24 (s, 1H), 5.19–5.12 (m, 2H), 4.57 (dd, J = 12.0, 2.9 Hz, 1H), 4.50–4.37 (m, 3H), 4.15–4.08 (m, 1H), 3.89 (t, J = 9.2 Hz, 1H), 3.78–3.71 (m, 4H), 3.39 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.3, 165.5, 165.3, 165.2, 165.1, 155.1, 150.3, 133.6, 133.5, 133.2, 133.1, 132.9, 130.00, 129.97, 129.81, 129.78, 129.72, 129.4, 129.3, 128.7, 128.5, 128.4, 128.33, 128.27, 118.5, 114.4, 110.1, 101.2, 97.2, 82.0, 73.0, 72.69, 72.68, 70.7, 69.1, 68.7, 63.6, 59.6, 58.9, 55.8; HRMS (ESI): *m*/*z* calcd for $C_{54}H_{52}O_{16}N$ $[M + NH_4]^+$ 970.3281, found 970.3288.

Benzyl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-α-D-xylopyranoside (34)

Following the procedure for the preparation of compound **29**, the coupling of **7c** (1.38 g, 3.07 mmol) and **8** (3.0 g, 4.61 mmol) in anhydrous CH_2Cl_2 (20 mL) in the presence of TMSOTf (56 μL, 0.022 mmol) afford **34** (2.30 g, 2.46 mmol, 80%) by silica gel column chromatography (toluene/EtOAc = 30/1). $[\alpha]_D^{24}$ = +1.0 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (d, J = 7.2 Hz, 2H), 8.02–7.95 (m, 4H), 7.93 (d, J = 7.2 Hz, 2H), 7.69 (t, J = 7.4 Hz, 1H), 7.63–7.50 (m, 5H), 7.49–7.35 (m, 6H), 7.33–7.22 (m, 3H), 7.20–7.12 (m, 5H), 7.12–7.04 (m, 2H), 5.30 (t, J = 9.5 Hz, 1H), 5.27–5.19 (m, 2H), 5.11 (d, J = 3.5 Hz, 1H), 5.06 (d, J = 8.0 Hz, 1H), 4.96 (dd, J = 9.4, 3.6 Hz, 1H), 4.69 (d, J = 12.3 Hz, 1H), 4.60 (t, J = 9.1 Hz, 1H), 4.48–4.39 (m, 2H), 4.31 (dd, J = 11.9, 5.9 Hz, 1H), 4.08–3.98 (m, 2H), 3.78 (t, J = 10.6 Hz, 1H), 3.70 (t, J = 9.3 Hz, 1H), 3.24 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.4, 165.6, 165.2, 165.1, 164.9, 137.0, 133.6, 133.3, 133.2, 133.0, 130.0, 129.93, 129.88, 129.79, 129.77, 129.68, 129.62, 129.59, 129.40, 129.35, 128.6, 128.5, 128.38, 128.35, 128.34, 128.0, 127.8, 101.5, 95.1, 81.9, 75.5, 73.9, 72.7, 72.2, 70.8, 69.9, 69.7, 63.9, 59.5, 59.2; HRMS (ESI): *m*/*z* calcd for $C_{54}H_{52}O_{15}N$ $[M + NH_4]^+$ 954.3331, found 954.3329.

2,4,6-Tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-α-D-xylopyranosyl trichloroacetimidate (35)

To a solution of **34** (2.58 mg, 2.75 mmol) in EtOH (70 mL) was added 10% Pd/C (1 g). The reaction vessel was evacuated and backfilled with hydrogen (1 atm). The mixture was stirred at 50 °C for 24 h, at this stage TLC indicated the reaction was completed. The mixture was filtered through a pad of Celite. The filtrate was concentrated and the residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 2.5/1) to afford the desired hemiacetal as a white foam which was directly used in the next step. To a soln of the above hemiacetal (1.91 g, 2.26 mmol) and Cl_3CCN (2.3 mL, 22.6 mmol) in CH_2Cl_2 (2.5 mL) was added DBU (171 μL, 1.15 mmol) at 0 °C. The mixture was stirred overnight at ambient temperature, and then concentrated *in vacuo*. The resulting residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 3.5/1) to afford **35** (2.02 g, 2.04 mmol, 74% over two steps). $[\alpha]_D^{24}$ = −15.7 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 (s, 1H), 8.11 (d, J = 7.5 Hz, 2H), 8.01 (d, J = 8.5 Hz, 2H), 7.99 (d, J = 8.5 Hz, 2H), 7.93 (d, J = 7.5 Hz, 2H), 7.71–7.54 (m, 4H), 7.54–7.45 (m, 5H), 7.42 (t, J = 7.7 Hz, 2H), 7.39–7.28 (m, 4H), 7.19 (t, J = 7.7 Hz, 2H), 6.49 (d, J = 3.4 Hz, 1H), 5.38–5.30 (m, 1H), 5.30–5.17 (m, 3H), 5.04 (d, J = 8.0 Hz, 1H), 4.60 (t, J = 9.2 Hz, 1H), 4.54 (dd, J = 12.0, 2.9 Hz, 1H), 4.29–4.17 (m, 2H), 4.12–4.04 (m, 1H), 3.87 (t, J = 10.8 Hz, 1H), 3.70 (t, J = 9.3 Hz, 1H), 3.23 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.4, 165.5, 165.3, 164.9, 164.8, 160.5, 133.73, 133.65, 133.5, 133.4, 133.1, 129.98, 129.95, 129.7, 129.6, 129.5, 129.30, 129.29, 129.0, 128.7, 128.6, 128.42, 128.38, 101.6, 93.7, 81.8, 77.2, 75.4, 72.6, 72.55, 72.48, 70.7, 68.8, 64.0, 61.7, 59.3; HRMS (ESI): *m*/*z* calcd for $C_{49}H_{46}O_{15}N_2Cl_3$ $[M + NH_4]^+$ 1007.1958, found 1007.1957.

p-Tolyl 2,3-di-*O*-benzoyl-6-deoxy-6-iodo-1-thio-β-D-glucopyranoside (37)

To a solution of **36** (1.13 g, 2.29 mmol), Ph_3P (1.20 g, 4.58 mmol) and imidazole (0.62 g, 9.16 mmol) in anhydrous THF (20 mL) was added a solution of I_2 (0.76 g, 2.98 mmol) in anhydrous THF (3 mL). After stirring for 1 h, monitoring by TLC indicated that the reaction went to completion. The mixture was filtered and the filtrate was concentrated *in vacuo*. The residue was purified by silica gel column chromatography to give **37** (petroleum ether/EtOAc = 5/1, 1.26 g, 2.08 mmol, 91%). $[\alpha]_D^{24}$ = +52.4 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98 (d, J = 8.0 Hz, 2H), 7.94 (d, J = 8.0 Hz, 2H), 7.57–7.45 (m, 4H), 7.44–7.32 (m, 4H), 7.13 (d, J = 7.9 Hz, 2H), 5.45–5.31 (m, 2H), 4.89 (d, J = 9.1 Hz, 1H), 3.79–3.65 (m, 2H), 3.47 (dd, J = 10.7, 6.4 Hz, 1H), 3.42–3.34 (m, 1H), 3.21 (s, 1H), 2.35 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.0, 165.3, 138.9, 134.4, 133.9, 133.5, 130.2, 130.0, 129.8, 129.4, 128.7, 128.6, 128.5, 127.5, 86.0, 79.0, 78.4, 73.3, 70.0, 21.4, 5.6; HRMS (ESI): *m*/*z* calcd for $C_{27}H_{29}O_6NIS$ $[M + NH_4]^+$ 622.0755, found 622.0743.

p-Tolyl 2,3-di-*O*-benzoyl-6-deoxy-1-thio-β-D-glucopyranoside (9)

To a solution of **19** (1.38 g, 2.28 mmol) in anydrous *N*,*N*-dimethylformamide (45 mL) was added 10% Pd/C (700 mg) and $NaHCO_3$ (633 mg, 7.53 mmol). The reaction vessel was evacuated and backfilled with hydrogen (1 atm). The mixture was stirred at 40 °C for 24 h. The solid was filtered on Celite and the filtrate was concentrated. The crude product was purified by silica gel column chromatography (petroleum ether/EtOAc = 5/

1) to give **9** (904 mg, 1.89 mmol, 83%). $[\alpha]_D^{24}$ = +89.7 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.02–7.90 (m, 4H), 7.56–7.48 (m, 2H), 7.42–7.33 (m, 6H), 7.11 (d, *J* = 8.1 Hz, 2H), 5.40 (t, *J* = 9.6 Hz, 1H), 5.32 (t, *J* = 9.0 Hz, 1H), 4.83 (d, *J* = 9.9 Hz, 1H), 3.65–3.49 (m, 2H), 2.93 (d, *J* = 4.4 Hz, 1H), 2.34 (s, 3H), 1.46 (d, *J* = 5.8 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 167.9, 165.4, 138.6, 133.7, 133.6, 133.4, 130.1, 129.9, 129.8, 129.5, 129.0, 128.6, 128.50, 128.49, 86.3, 78.8, 74.7, 70.6, 21.3, 18.0; HRMS (ESI): *m*/*z* calcd for $C_{27}H_{30}O_6NS$ $[M + NH_4]^+$ 496.1788, found 496.1786.

p-Tolyl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranosyl-(1→4)-2,3-di-*O*-benzoyl-6-deoxy-1-thio-β-D-glucopyranoside (4)

A solution of **35** (1.24 g, 1.25 mmol) and **9** (400 mg, 0.84 mmol) in anhydrous CH_2Cl_2 (12 mL) was stirred vigorously in the presence of activated 4 Å molecular sieves (1 g) for 20 min. The mixture was cooled to 0 °C and TMSOTf (15 μL, 0.084 mmol) were added. After 1 h, the reaction mixture was quenched with Et_3N and filtered. The filtrate was concentrated *in vacuo*. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 3/1) to give **4** (756 mg, 70%). $[\alpha]_D^{24}$ = +2.6 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.01 (s, 2H), 7.98 (s, 2H), 7.96 (d, *J* = 7.7 Hz, 2H), 7.93 (d, *J* = 7.7 Hz, 2H), 7.89 (d, *J* = 7.8 Hz, 4H), 7.80 (d, *J* = 7.7 Hz, 2H), 7.60–7.07 (m, 24H), 5.48 (t, *J* = 9.2 Hz, 1H), 5.37 (t, *J* = 9.4 Hz, 1H), 5.32 (t, *J* = 8.3 Hz, 1H), 5.23 (t, *J* = 9.7 Hz, 1H), 5.03–4.97 (m, 1H), 4.97–4.88 (m, 2H), 4.74 (d, *J* = 2.8 Hz, 1H), 4.63 (d, *J* = 10.1 Hz, 1H), 4.47 (dd, *J* = 11.9, 3.0 Hz, 1H), 4.33 (dd, *J* = 12.0, 6.3 Hz, 1H), 4.21 (t, *J* = 4.5 Hz, 1H), 4.06–3.96 (m, 1H), 3.93 (dd, *J* = 12.7, 2.4 Hz, 1H), 3.73 (t, *J* = 9.2 Hz, 1H), 3.42 (t, *J* = 9.2 Hz, 1H), 3.32 (s, 3H), 3.22–3.15 (m, 1H), 3.11 (dd, *J* = 12.7, 4.0 Hz, 1H), 2.35 (s, 3H), 1.10 (t, *J* = 6.0 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 165.6, 165.5, 165.3, 165.2, 164.9, 164.7, 138.4, 133.6, 133.44, 133.37, 133.27, 133.26, 133.19, 133.00, 132.95, 130.02, 129.94, 129.91, 129.8, 129.7, 129.6, 129.4, 129.2, 129.0, 128.63, 128.59, 128.5, 128.43, 128.40, 128.32, 128.27, 101.2, 100.0, 86.2, 82.7, 81.7, 75.4, 74.8, 74.0, 72.7, 72.5, 71.5, 70.6, 70.3, 68.8, 63.7, 59.6, 18.0; HRMS (ESI): *m*/*z* calcd for $C_{74}H_{70}O_{20}NS$ $[M + NH_4]^+$ 1324.4206, found 1324.4198.

Lanost-7-en-3β-yl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranosyl-(1→4)-2,3-di-*O*-benzoyl-6-deoxy-β-D-glucopyranosyl-(1→2)-3-*O*-benzoyl-4-*O*-(2-naphthylmethyl)-β-D-xylopyranoside (2)

A solution of **3** (62 mg, 0.076 mmol) and **4** (150 mg, 0.115 mmol) in anhydrous CH_2Cl_2 (2 mL) was stirred vigorously in the presence of activated 4 Å molecular sieves (200 mg) for 20 min. The mixture was cooled to 0 °C and NIS (34 mg, 0.152 mmol) and TMSOTf (2 μL, 0.008 mmol) were added. After stirring for 2 h, the reaction mixture was quenched with Et_3N, and the solid was filtered off. The filtrate was washed with saturated aqueous $Na_2S_2O_3$ and brine. The organic phase was dried over Na_2SO_4, filtered and concentrated. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 3.5/1) to give **2** (134 mg, 67%). $[\alpha]_D^{24}$ = +10.6 (*c* 0.75, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (d, *J* = 7.3 Hz, 2H), 7.94–7.81 (m, 10H), 7.78 (d, *J* = 7.3 Hz, 2H), 7.74–7.65 (m, 3H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.60–7.49 (m, 5H), 7.49–7.43 (m, 5H), 7.43–7.35 (m, 8H), 7.32–7.24 (m, 8H), 7.18 (t, *J* = 7.8 Hz, 2H), 7.14 (dd, *J* = 8.4, 1.2 Hz, 1H), 5.36–5.23 (m, 4H), 5.21 (s, 1H), 5.16 (t, 8.1 Hz, 1H), 5.03–4.97 (m, 1H), 4.97–4.93 (m, 1H), 4.87 (d, *J* = 7.8 Hz, 1H), 4.71 (d, *J* = 7.9 Hz, 1H), 4.64 (d, *J* = 4.0 Hz, 1H), 4.59–4.46 (m, 3H), 4.42 (dd, *J* = 12.0, 3.2 Hz, 1H), 4.28 (dd, *J* = 11.9, 6.3 Hz, 1H), 4.17 (t, *J* = 5.6 Hz, 1H), 4.04–3.90 (m, 2H), 3.86–3.75 (m, 2H), 3.67 (t, *J* = 9.2 Hz, 1H), 3.52–3.61 (m, 1H), 3.39–3.31 (m, 2H), 3.29 (s, 3H), 3.25–3.16 (m, 1H), 3.09 (dd, *J* = 11.7, 3.6 Hz, 1H), 3.05 (dd, *J* = 12.6, 5.0 Hz, 1H), 2.04–1.88 (m, 4H), 1.82–1.71 (m, 2H), 1.04 (s, 3H), 1.02–0.97 (m, 6H), 0.91–0.83 (m, 15H), 0.64 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 165.6, 165.5, 165.3, 165.2, 164.8, 164.7, 145.1, 135.2, 133.6, 133.42, 133.40, 133.2, 133.1, 133.04, 133.00, 132.8, 132.7, 130.1, 130.0, 129.97, 129.93, 129.90, 129.87, 129.8, 129.7, 129.6, 129.4, 129.2, 128.7, 128.6, 128.5, 128.4, 128.3, 128.23, 128.19, 128.0, 127.7, 126.8, 126.1, 126.0, 125.9, 116.8, 103.7, 101.5, 100.5, 100.4, 90.2, 83.1, 81.7, 76.4, 75.2, 74.6, 74.4, 73.7, 72.70, 72.68, 72.4, 72.1, 71.0, 70.9, 70.6, 69.1, 63.7, 62.5, 60.2, 59.3, 52.1, 51.0, 50.7, 47.3, 44.5, 39.7, 39.2, 38.3, 36.7, 36.6, 35.4, 32.32, 32.26, 28.2, 27.8, 26.3, 25.0, 24.3, 23.0, 22.7, 20.2, 19.1, 17.6, 16.4, 16.2, 14.2; HRMS (ESI): *m*/*z* calcd for $C_{120}H_{130}O_{26}Na$ $[M + Na]^+$ 2009.8743, found 2009.8736.

Lanost-7-en-3β-yl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranosyl-(1→4)-2,3-di-*O*-benzoyl-6-deoxy-β-D-glucopyranosyl-(1→2)-3-*O*-benzoyl-β-D-xylopyranoside (38)

To a solution of **2** (100 mg, 0.05 mmol) in CH_2Cl_2 (2.80 mL) and MeOH (0.80 mL) was added DDQ (34 mg, 0.15 mmol) in three portions at half an hour interval. After 5 h, the reaction was completed and the volatile was removed by evaporation. The residue was taken up in dichloromethane and washed with saturated aqueous $NaHCO_3$ and brine. The collected organic phase was dried over Na_2SO_4, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/EtOAc = 2.5/1) to give **38** (81 mg, 88%). $[\alpha]_D^{24}$ = −2.5 (*c* 1.05, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.11–7.97 (m, 6H), 7.96–7.83 (m, 8H), 7.79 (d, *J* = 7.3 Hz, 2H), 7.66–7.53 (m, 3H), 7.52–7.38 (m, 10H), 7.38–7.19 (m, 9H), 7.15 (t, *J* = 7.8 Hz, 2H), 5.48 (t, *J* = 9.4 Hz, 1H), 5.42–5.31 (m, 2H), 5.26–5.20 (m, 1H), 5.18 (s, 1H), 5.03–4.98 (m, 1H), 4.98–4.95 (m, 1H), 4.94 (d, *J* = 7.8 Hz, 1H), 4.88 (t, *J* = 4.0 Hz, 1H), 4.82 (s, 1H), 4.76–4.67 (m, 2H), 4.47 (dd, *J* = 12.0, 3.2 Hz, 1H), 4.34 (dd, *J* = 12.0, 6.3 Hz, 1H), 4.25 (dd, *J* = 10.1, 1.8 Hz, 1H), 4.22 (t, *J* = 4.7 Hz, 1H), 4.04–3.97 (m, 1H), 3.94 (dd, *J* = 12.6, 2.6 Hz, 1H), 3.90 (s, 1H), 3.75 (t, *J* = 9.2 Hz, 1H), 3.64–3.56 (m, 1H), 3.53 (dd, *J* = 12.3, 2.9 Hz, 1H), 3.43 (t, *J* = 9.2 Hz, 1H), 3.33 (s, 3H), 3.19–3.03 (m, 4H), 1.01 (d, *J* = 6.0 Hz, 3H), 0.97 (s, 3H), 0.91–0.85 (m, 12H), 0.84 (s, 3H), 0.67 (s, 3H), 0.64 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 166.04, 166.00, 165.5, 165.3, 165.2, 164.9, 164.7, 145.2, 133.6, 133.6, 133.5, 133.4, 133.2, 133.2, 133.1, 133.0, 130.1, 130.00, 129.96, 129.9, 129.78, 129.75, 129.74, 129.6, 129.42, 129.38, 129.2, 128.7, 128.6, 128.5, 128.44, 128.43, 128.33, 128.29, 116.6, 102.1, 101.3, 101.0, 100.1, 89.6, 82.9, 81.7, 77.4, 73.9, 73.7, 73.2, 72.72, 72.69, 72.5, 71.2, 70.6, 70.3, 68.8, 67.1, 63.7, 61.7, 59.6, 59.3, 52.1, 51.0, 50.5, 47.3, 44.5, 39.7, 39.1, 38.3, 36.7, 36.6,

35.4, 32.3, 32.2, 28.3, 28.2, 27.8, 26.2, 25.0, 24.3, 23.00, 22.98, 22.7, 20.2, 19.1, 17.5, 16.3, 16.2, 14.3; HRMS (ESI): *m*/*z* calcd for $C_{109}H_{126}O_{26}N$ $[M + NH_4]^+$ 1864.8563, found 1864.8521.

Lanost-7-en-3β-yl 2,4,6-tri-*O*-benzoyl-3-*O*-methyl-β-D-glucopyranosyl-(1→3)-2,4-di-*O*-benzoyl-β-D-xylopyranosyl-(1→4)-2,3-di-*O*-benzoyl-6-deoxy-β-D-glucopyranosyl-(1→2)-3-*O*-benzoyl-4-*O*-sulfo-β-D-xylopyranoside (39)

To a mixture of alcohol **38** (60 mg, 0.032 mmol) in anhydrous pyridine (2.0 mL) was added sulfur trioxide/pyridine complex (103 mg, 0.65 mmol). The sealed Pyrex tube was irradiated in the microwave (100 W, CEM corporation, Matthews, North Carolina, USA) at 100 °C for 2 h. After cooling, water (1 mL) was added to the mixture, which was then concentrated *in vacuo*. The residue was purified by silica gel column chromatography (CH_2Cl_2/MeOH = 13/1) to give **39** (60 mg, 0.03 mmol, 94%). $[\alpha]_D^{24}$ = +2.8 (*c* 1.00, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, *J* = 5.4 Hz, 2H), 7.99 (d, *J* = 7.5 Hz, 2H), 7.97 (d, *J* = 7.5 Hz, 2H), 7.93 (d, *J* = 7.6 Hz, 2H), 7.87 (d, *J* = 6.5 Hz, 4H), 7.79 (d, *J* = 7.5 Hz, 2H), 7.63 (d, *J* = 7.6 Hz, 2H), 7.60–7.52 (m, 3H), 7.50 (t, *J* = 7.3 Hz, 1H), 7.47–7.30 (m, 11H), 7.29–7.19 (m, 4H), 7.15 (t, *J* = 7.6 Hz, 2H), 7.10–7.00 (m, 1H), 6.73–6.54 (m, 2H), 5.46 (t, *J* = 9.0 Hz, 1H), 5.39–5.24 (m, 3H), 5.19 (s, 1H), 5.04–4.97 (m, 2H), 4.97–4.81 (m, 3H), 4.72 (s, 1H), 4.61 (d, *J* = 7.8 Hz, 1H), 4.52–4.39 (m, 2H), 4.34 (d, *J* = 11.9 Hz, 1H), 4.29 (dd, *J* = 11.8, 6.1 Hz, 1H), 4.20 (t, *J* = 4.8, 1H), 3.99–3.88 (m, 2H), 3.88–3.78 (m, 2H), 3.76–3.60 (m, 1H), 3.49 (t, *J* = 9.0 Hz, 1H), 3.29 (s, 3H), 3.16–3.08 (m, 1H), 3.08–2.98 (m, 2H), 1.00 (d, *J* = 5.5 Hz, 3H), 0.98 (s, 3H), 0.83 (s, 3H), 0.64 (s, 3H), 0.62 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.2, 165.7, 165.4, 165.3, 165.2, 164.9, 164.7, 145.1, 133.5, 133.4, 133.3, 133.2, 133.0, 130.3, 130.03, 129.93, 129.88, 129.71, 129.70, 129.6, 129.5, 129.4, 129.2, 128.9, 128.64, 128.60, 128.5, 128.4, 128.3, 128.0, 127.9, 116.6, 102.16, 102.14, 101.1, 100.5, 90.0, 82.6, 81.7, 75.0, 74.4, 73.7, 72.8, 72.7, 72.4, 71.4, 71.2, 70.7, 70.6, 68.8, 63.7, 62.9, 60.0, 59.3, 52.1, 51.0, 50.5, 47.3, 44.5, 39.7, 39.1, 38.3, 36.7, 36.6, 35.4, 32.3, 32.2, 32.1, 30.3, 29.8, 29.7, 29.5, 28.5, 28.1, 27.8, 26.1, 25.0, 24.3, 23.0, 22.8, 22.7, 20.2, 19.1, 17.5, 16.2, 16.2, 14.2; HRMS (ESI): *m*/*z* calcd for $C_{109}H_{122}O_{29}S$ $[M - Na]^-$ 1926.7787, found 1926.7743.

Sodium salt of lanost-7-en-3β-yl 3-*O*-methyl-β-D-glucopyranosyl-(1→3)-β-D-xylopyranosyl-(1→4)-6-deoxy-β-D-glucopyranosyl-(1→2)-4-*O*-sulfo-β-D-xylopyranoside (1)

To a solution **39** (50 mg, 0.026 mmol) in 9 mL of anhydrous methanol/CH_2Cl_2 (v/v = 2/1) was added a solution of sodium methoxide (1.04 mL, 1.04 mmol, 1 M) in methanol. After the resulting mixture was stirred at rt for 30 h, it was diluted with water, and then concentrated under reduced pressure. The residue was dialyzed against water followed by lyophilization to afford **1** (25 mg, 86%). $[\alpha]_D^{24} = -7.0$ (*c* 0.25, H_2O); ^{1}H NMR (500 MHz, pyridine-d_5) δ 5.40 (d, *J* = 7.6 Hz, 1H), 5.35 (s, 1H), 5.26–4.90 (m, 4H), 4.87 (d, *J* = 7.3 Hz, 1H), 4.81–4.63 (m, 2H), 4.49 (d, *J* = 10.6 Hz, 1H), 4.40–4.19 (m, 4H), 4.18–3.93 (m, 7H), 3.88 (s, 3H), 3.82–3.53 (m, 5H), 3.26 (d, 1H), 1.74 (d, *J* = 5.4 Hz, 3H), 1.26 (s, 3H), 1.19 (s, 3H), 1.11 (s, 3H), 0.99 (d, *J* = 8.6 Hz, 3H), 0.98 (s, 3H), 0.92 (d, *J* = 6.5 Hz, 6H), 0.76 (s, 3H); ^{13}C NMR (126 MHz, pyridine-d_5) δ 145.8, 117.7, 106.0, 105.9, 105.7, 89.6, 88.5, 87.6, 86.5, 84.0, 78.7, 76.8, 76.2, 76.1, 75.8, 75.6, 74.3, 72.3, 71.1, 69.4, 67.1, 64.9, 62.5, 61.4, 52.8, 51.7, 51.4, 48.0, 45.2, 40.3, 40.0, 38.8, 37.33, 37.27, 36.0, 33.1, 32.9, 28.8, 28.7, 28.4, 27.5, 25.5, 25.0, 23.7, 23.5, 23.2, 20.8, 19.7, 18.5, 17.1, 16.8, 14.9; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{89}O_{21}S$ $[M - Na]^-$ 1093.5621, found 1093.5625.

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Notes and references

1 K. Hostettmann and A. Marston, *Saponins*, Cambridge University Press, New York, 1995.

2 (*a*) V. I. Kalinin, A. S. Silchenko, S. A. Avilov, V. A. Stonik and A. V. Smirnov, *Phys. Rev.*, 2005, **4**, 221–236; (*b*) S.-K. Kim, S. W. A. Himaya and K.-H. Kang, *Marine Pharmacognosy Trends and Applications*, ed. S.-K. Kim, CRC Press, Boca Raton, 2013, pp. 119–127; (*c*) D. L. Aminin, E. A. Pislyagin, E. S. Menchinskaya, A. S. Silchenko, S. A. Avilov and V. I. Kalinin, *Studies in Natural Product Chemistry*, ed. A. Rahman, Elsevier, Kidlington, 2014, pp. 75–94.

3 (*a*) Y.-H. Yi, Q.-Z. Xu, L. Li, S.-L. Zhang, H.-M. Wu, J. Ding, Y.-G. Tong, W.-F. Tan, M.-H. Li, F. Tian, J.-H. Wu, C.-C. Liaw, K. F. Bastow and K.-H. Lee, *Helv. Chim. Acta*, 2006, **89**, 54–63; (*b*) S.-L. Zhang, L. Li, Y.-H. Yi and P. Sun, *Nat. Prod. Res.*, 2006, **20**, 399–407.

4 F. Tian, C.-H. Zhu, X.-W. Zhang, X. Xie, X.-L. Xin, Y.-H. Yi, L.-P. Lin, M.-Y. Geng and J. Ding, *Mol. Pharmacol.*, 2007, **72**, 545–552.

5 (*a*) H. Pellissier, *Tetrahedron*, 2004, **60**, 5123–5162; (*b*) B. Yu, Y. Zhang and P. Tang, *Eur. J. Org. Chem.*, 2007, 5145–5161; (*c*) B. Yu and J. Sun, *Chem.–Asian J.*, 2009, **4**, 642–654; (*d*) C. Gauthier, J. Legault and A. Pichette, *Org. Chem.*, 2009, **6**, 321–344; (*e*) C. Gauthier, J. Legault, M. Piochon-Gauthier and A. Pichette, *Phytochem. Rev.*, 2011, **10**, 521–544; (*f*) B. Yu, J. Song and X. Yang, *Acc. Chem. Res.*, 2012, **45**, 1227–1236; (*g*) Y. Yang, S. Laval and B. Yu, *Adv. Carbohydr. Chem. Biochem.*, 2014, **71**, 137–226; (*h*) L. Zu, Y. Zhao and G. Gu, *J. Carbohydr. Chem.*, 2014, **33**, 269–297; (*i*) Y. Yang, X. Zhang and B. Yu, *Nat. Prod. Rep.*, 2015, **32**, 1331–1355.

6 For the synthesis of lanostano-18,20-lactone aglycones, see: (*a*) G. Habermehl, K.-H. Seib and K.-P. Swiderskjj, *Liebigs Ann. Chem.*, 1978, 419–426; (*b*) G. G. Habermehl and J. H. Kirsch, *Toxicon*, 1983, 179–181. For the recent efforts to synthesis of sea cucumber triterpene glycosides, see: (*c*) J. Yu and B. Yu, *Chin. Chem. Lett.*, 2015, **26**, 1331–1335.

7 A. V. Demchenko, *Handbook of Chemical Glycosylation: Advances in Stereoselectivity and Therapeutic Relevance*, ed. A. V. Demchenko, WILEY-VCH, Weinheim, 2008, pp. 1–28.

8 (*a*) Y.-P. Hu, Y.-Q. Zhong, Z.-G. Chen, C.-Y. Chen, Z. Shi, M. M. L. Zulueta, C.-C. Ku, P.-Y. Lee, C.-C. Wang and S.-C. Hung, *J. Am. Chem. Soc.*, 2012, **134**, 20722–20727; (*b*) G. Xiao and B. Yu, *Chem.–Eur. J.*, 2013, **19**, 7708–7712; (*c*) S. U. Hansen, G. J. Miller, G. C. Jayson and J. M. Gardiner, *Org. Lett.*, 2013, **15**, 88–91; (*d*) Y. Dai and B. Yu, *Chem. Commun.*, 2015, **51**, 13826–13829.

9 (*a*) M. Masaoud, J. Schmidt and G. Adam, *Phytochemistry*, 1995, **38**, 795–796; (*b*) C. Areche, P. Cejas, P. Thomas, A. San-Martín, L. Astudillo, M. Gutiérrez and L. A. Loyola, *Quim. Nova*, 2009, **32**, 2023–2025.

10 (*a*) R. E. Marker, E. L. Wittle and L. W. Mixon, *J. Am. Chem. Soc.*, 1937, **59**, 1368–1373; (*b*) R. B. Woodward, A. A. Patchett, D. H. R. Barton, D. A. J. Ives and R. B. Kelly, *J. Chem. Soc.*, 1957, 1131–1144.

11 B. B. Shingate, B. G. Hazra, D. B. Salunke, V. S. Pore, F. Shirazi and M. V. Deshpande, *Tetrahedron*, 2013, **69**, 11155–11163.

12 V. A. Ignatenko and G. P. Tochtrop, *J. Org. Chem.*, 2013, **78**, 3821–3831.

13 (*a*) K. Takahashi, K. Usami, T. Takahashi, T. Okada and M. Morisaki, *Chem. Pharm. Bull.*, 1987, **35**, 3467–3469; (*b*) G. G. Habermehl, J. H. Kirsch and K. J. Reibstein, *Heterocycles*, 1982, **17**, 183–189.

14 CCDC 1419939 (**14**·MeOH)†

15 M. Balci, *Basic ^{1}H- and ^{13}C-NMR Spectroscopy*, Elsevier, Kidlington, 2005, pp. 87–133.

16 (*a*) D. H. R. Barton and S. W. McCombie, *J. Chem. Soc., Perkin Trans. 1*, 1975, 1574–1585; (*b*) N. Martin and E. J. Thomas, *Org. Biomol. Chem.*, 2012, **10**, 7952–7964; (*c*) M. M. Heravi, A. Bakhtiari and Z. Faghihi, *Curr. Org. Synth.*, 2014, **11**, 787–823.

17 M. S. Reddy, H. Zhang, S. Phoenix and P. Deslongchamps, *Chem.–Asian J.*, 2009, **4**, 725–741.

18 Q. Liu, T. Guo, L. Zhang, Y. Yu, P. Wang, J. Yang and Y. Li, *Eur. J. Med. Chem.*, 2013, **63**, 511–522.

19 R. H. Purdy, A. L. Morrow, J. R. Blinn and S. M. Paul, *J. Med. Chem.*, 1990, **33**, 1572–1581.

20 (*a*) P. J. Stang, M. Hanack and L. R. Subramanian, *Synthesis*, 1982, 85–126; (*b*) E. R. Binkley and R. W. Binkley, *Preparative Carbohydrate Chemistry*, ed. S. Hanessian, Marcel Dekker Inc., New York, 1997, pp. 87–104.

21 R. R. Kumar, S. D. Haveli and H. B. Kagan, *Synlett*, 2011, 1709–1712.

22 T. Itoh, T. Tamura and T. Matsumoto, *Steroids*, 1976, **27**, 275–285.

23 B. Yang, K. Yoshida, Z. Yin, H. Dai, H. Kavunja, M. H. Eldakdouki, S. Sungsuwan, S. B. Dulaney and X. Huang, *Angew. Chem., Int. Ed.*, 2012, **51**, 10185–10189.

24 (*a*) S. David and S. Hanessian, *Tetrahedron*, 1985, **41**, 643–663; (*b*) R. F. Helm, J. Ralph and L. Anderson, *J. Org. Chem.*, 1991, **56**, 7015–7021.

25 (*a*) K. R. Love, R. B. Andrade and P. H. Seeberger, *J. Org. Chem.*, 2001, **66**, 8165–8176; (*b*) W. Peng, J. Sun, X. Han and B. Yu, *Synlett*, 2004, 259–262; (*c*) K. R. Love and P. H. Seeberger, *J. Org. Chem.*, 2005, **70**, 3168–3177.

26 B. Ren, M. Rahm, X. Zhang, Y. Zhou and H. Dong, *J. Org. Chem.*, 2014, **79**, 8134–8142.

27 I. Lundt, C. Pedersen and B. Tronier, *Acta Chem. Scand.*, 1964, **18**, 1917–1922.

28 (*a*) H. Yu, B. Yu, X. Wu, Y. Hui and X. Han, *J. Chem. Soc., Perkin Trans. 1*, 2000, 1445–1453; (*b*) T. Zhu and G.-J. Boons, *Carbohydr. Res.*, 2000, **329**, 709–715; (*c*) Z. Li and J. C. Gildersleeve, *J. Am. Chem. Soc.*, 2006, **128**, 11612–11619; (*d*) S.-S. Chang, C.-H. Shih, K.-C. Lai and K.-K. T. Mong, *Chem.–Asian J.*, 2010, **5**, 1152–1162.

29 J. Tamura, A. Yamaguchi, J. Tanaka and Y. Nishimura, *J. Carbohydr. Chem.*, 2007, **26**, 61–82.

30 F. Kong, *Carbohydr. Res.*, 2007, **342**, 345–373.

31 (*a*) E. Petráková and J. Schraml, *Chem. Commun.*, 1983, **48**, 877–888; (*b*) A. D. Bruyn, M. Anteunis, R. V. Rijsbergen, M. Claeyssens and P. Kováč, *J. Carbohydr. Chem.*, 1983, **1**, 301–309; (*c*) R. F. Helm and J. Ralph, *Carbohydr. Res.*, 1993, **240**, 23–38; (*d*) H. Yuasa, N. Miyagawa, M. Nakatani, M. Izumi and H. Hashimoto, *Org. Biomol. Chem.*, 2004, **2**, 3548–3556.

32 (*a*) S. Karamat and W. M. F. Fabian, *J. Phys. Chem. A*, 2006, **110**, 7477–7484; (*b*) Ž. J. Vitnik and W. M. F. Fabian, *Comput. Theor. Chem.*, 2015, **1051**, 104–109.

33 (*a*) B. Yu and Z. Yang, *Org. Lett.*, 2001, **3**, 377–379; (*b*) Q. Yang, M. Lei, Q.-J. Yin and J.-S. Yang, *Carbohydr. Res.*, 2007, **342**, 1175–1181.

34 M.-C. Yan, Y.-N. Chen, H.-T. Wu, C.-C. Lin, C.-T. Chen and C.-C. Lin, *J. Org. Chem.*, 2007, **72**, 299–302.

35 (*a*) A. Raghuraman, M. Riaz, M. Hindle and U. R. Desai, *Tetrahedron Lett.*, 2007, **48**, 6754–6758; (*b*) R. A. Al-Horani, P. Ponnusamy, A. Y. Mehta, D. Gailani and U. R. Desai, *J. Med. Chem.*, 2013, **56**, 867–878; (*c*) P. Xu, W. Xu, Y. Dai, Y. Yang and B. Yu, *Org. Chem. Front.*, 2014, **1**, 405–414.