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Allyl protecting group mediated intramolecular aglycon delivery: optimisation of mixed acetal formation and mechanistic investigation

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Abstract—An efficient protocol for the formation of α-iodo mixed acetals, the first step of allyl-mediated IAD, by reaction of allyl-derived enol ethers and alcohols, using I_2, AgOTf and di-*tert*-butyl methylpyridine as a novel source of I^+, is reported. This reagent combination is capable of tethering glycosyl donors to the secondary alcohol groups of a variety of glycosyl acceptors including mono-, di- and trisaccharides. Mechanistic studies confirm the intramolecular nature of the glycosylation reaction, whilst the attempted use of diol glycosyl acceptors reveals limitations of both regio- and stereoselectivity in the glycosylation step.

1. Introduction

Control of anomeric stereochemistry during the course of a glycosylation reaction is a key consideration when undertaking the synthesis of any glycoside or oligosaccharide. In the majority of cases, 1,2-*trans* glycosidic linkages, wherein the anomeric substituent is formally *trans* to the 2-hydroxyl of the glycosyl donor, may be synthesised with high levels of stereocontrol by taking advantage of classical neighbouring group participation of 2-*O*-acyl protected glycosyl donors.[1] However, the synthesis of 1,2-*cis* glycosidic linkages is considerably more difficult.[2] Several research groups have sought to solve the perennial problem of stereochemical control of glycosylation by investigating the use of intramolecular glycosylation reactions.[3] Intramolecular aglycon delivery or IAD, is a particular intramolecular glycosylation strategy aimed at the stereospecific synthesis of 1,2-*cis* glycosides wherein the glycosyl acceptor is temporarily appended to the 2-hydroxyl group of a glycosyl donor.[4] This first so-called 'tethering' step, that is, the linking of donor and acceptor, is then followed by activation of the glycosyl donor, which subsequently furnishes the 1,2-*cis* glycoside in a completely stereoselective fashion via an intramolecular glycosylation reaction.

The IAD approach was originally conceived by Barresi and Hindsgaul,[5] and Stork and co-workers[6] for the synthesis of the β-mannosyl linkage, which is notoriously difficult to synthesise.[7] Following on from these initial reports, Ogawa and co-workers reported the development of a considerably more efficient and reliable IAD approach for the synthesis of β-mannosides based on the use of 2-*O*-*para*-methoxybenzyl (PMB) protected glycosyl donors.[8] This approach has also been applied to the syntheses of other 1,2-*cis* glycosides with varying degrees of success.[9] As part of our own programme[10] into the development of a reliable and widely applicable synthetic methodology that will allow the formation of 1,2-*cis* glycosidic linkages with complete stereocontrol, we recently reported the development of an allyl protecting group mediated IAD approach (allyl IAD)[11] based on either thioglycoside[12] or glycosyl fluoride donors.[13] This methodology relies on tethering of an aglycon alcohol to an enol ether at the 2-position of a glycosyl donor, itself derived from a 2-*O*-allyl protected donor by Wilkinson's catalyst mediated isomerisation[14] of the

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double bond. Previous studies have focused on the use of *N*-iodosuccinimide (NIS) as an iodonium ion source to form α-iodo mixed acetals such as **1** in the tethering step. Subsequent activation of the glycosyl donor by the addition of an appropriate promoter then furnishes the 1,2-*cis* glycoside **2** with complete control of anomeric stereochemistry (Fig. 1).

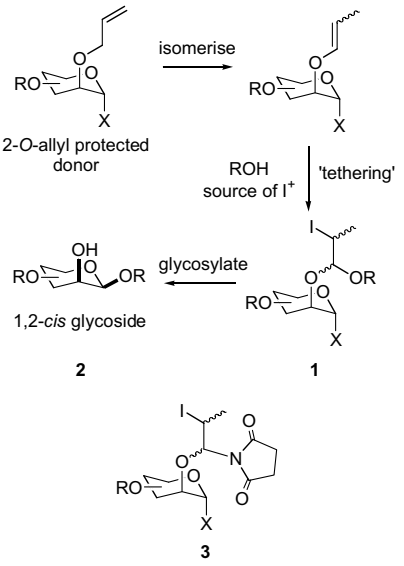


Figure 1.

However, the formation of mixed acetals **1** was found to be quite inefficient for more hindered aglycon alcohols, and in particular, succinimide-trapped acetals such as **3** were sometimes formed as the major products, a result which precludes the use of this methodology more generally for oligosaccharide synthesis. Indeed nucleophilic trapping by succinimide has been reported in other systems where NIS is employed as an iodonium ion source.[15] Herein we report the use of a novel source of I^+ that allows greatly increased efficiency of tethering of glycosyl donor and acceptor and the formation of mixed acetals **1** in high yield. In addition, crossover experiments are detailed, which confirm the intramolecular nature of the subsequent glycosylation reaction. Finally, some unexpected limitations are revealed, which highlight the important problems of regio- and stereocontrol that must be considered when designing any intramolecular glycosylation strategy.

2. Results and discussion

2.1. Optimisation of mixed acetal formation

The formation of succinimide-trapped species, such as **3**, indicated a fundamental limitation in the use of NIS as a source of iodonium ions for the efficient formation of mixed acetals from hindered secondary carbohydrate alcohols. It was postulated that increased yields of mixed acetals could be achieved by the use of an iodonium source with a non-nucleophilic counter ion. Iodonium di-sym-collidine triflate (IDCT), which has been proposed[16] as an alternative to the more commonly used[17] iodonium di-sym-collidine perchlorate (IDCP),[18] was therefore deemed a potential source of I^+. In this case, the counter ion is triflate, and it was postulated that even if the ionic intermediate **4** (either the cyclic iodonium ion or the non-bridged oxonium ion) was attacked competitively by the triflate in preference to the aglycon alcohol, then the resultant acetal triflate **5** would itself be sufficiently labile to eventually lead to the formation of the desired mixed acetal product **1** (Fig. 2).

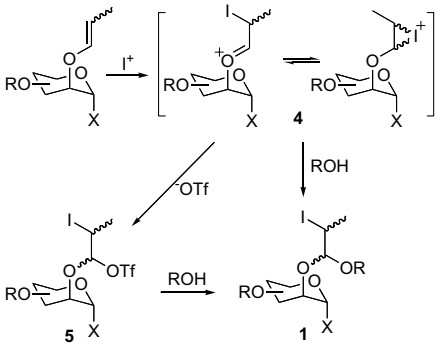
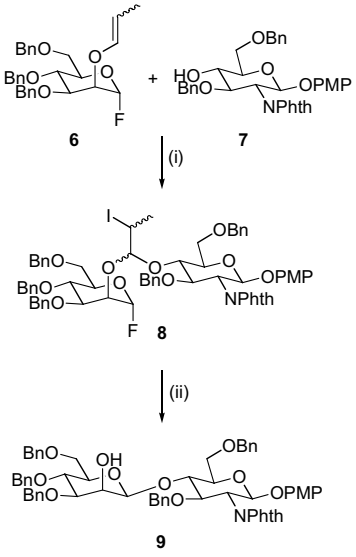


Figure 2.

As a test reaction, IDCT-mediated mixed acetal formation from the *manno* enol ethers **6**[13] and the hindered glucosamine alcohol **7**[19] was investigated as a possible 'worst-case' scenario, since previous attempts at NIS-mediated tethering of acceptors such as **7** with enol ethers derived from 2-*O*-allyl donors had only produced a very low yield of the desired mixed acetals.[12b] IDCT is most readily generated in situ by reaction of iodine, silver triflate and collidine and it was found that when *manno* enol ethers **6** and aglycon alcohol **7** were added to such a mixture, tethering did take place to give an acceptable 60% yield of **8**;[12b] a significant improvement on the previous NIS-mediated reaction. However, monitoring of this IDCT-mediated reaction revealed that after initial rapid formation of some of the desired tethered material **8**, the reaction seemed to stop rather than proceed to completion, despite the use of excess reagents. Interestingly, attempted mixed acetal formation using iodine and collidine alone produced no reaction. In addition, it was also found that NIS-mediated tethering reactions did not work at all in the presence of pyridine and other unhindered amine bases instead of collidine, but that they did proceed in the presence of the hindered base di-*tert*-butyl methylpyridine (DTBMP). Consequently, it was proposed that a better source of I^+ to be used in a tethering reaction could be generated in situ from I_2, AgOTf and DTBMP, a previously unused combination of reagents. Indeed, when a tethering reaction of **6** and **7** was carried out under these conditions, using only 1 equiv of all reagents, the desired mixed acetals **8** were formed in 75% yield. Intramolecular glycosylation of mixed acetals **8**, mediated by tin(II) chloride and AgOTf in the presence of DTBMP, then produced the Manβ(1→4)GlcNAc disaccharide **9**, which forms part of the core *N*-glycan pentasaccharide, in a

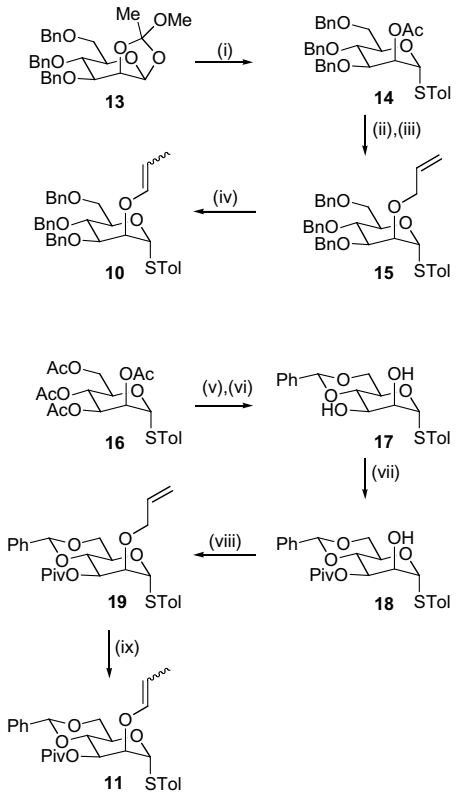
respectable 54% yield as the sole glycosylated reaction product (Scheme 1). It seemed therefore that this new reagent combination was optimal for mixed acetal formation,[20] and represented a marked improvement on both the NIS- and IDCT-mediated versions. A series of tethering reactions under these new conditions (I_2, AgOTf and DTBMP) was therefore attempted for a variety of different donors **10**, **11**, **12**[13] and **6**. New glycosyl donors were synthesised as follows (Scheme 2). Donor **10** was synthesised from the known orthoester **13**[21] by treatment with *para*-thiocresol to give thioglycoside **14**, which was then converted into 2-*O*-allyl thioglycoside **15** by sequential deprotection with sodium methoxide and methanol, and then treatment with allyl bromide and sodium hydride. Isomerisation of the allyl group using Wilkinson's catalyst then yielded enol ethers **10**. Donor **11** was synthesised from tetraacetate **16**[22] by sequential deacetylation and immediate benzylidenation to yield predominantly the monobenzylidene derivative **17**. Selective pivaloylation of the 3-hydroxyl yielded alcohol **18**, was then treated with allyl bromide and sodium hydride to yield allyl ether **19**. Finally, Wilkinson's catalyst mediated isomerisation yielded enol ethers **11** (Scheme 2).



Scheme 1. Reagents and conditions: (i) I_2, AgOTf, DTBMP, CH_2Cl_2, 4 Å molecular sieves, −78 °C to room temperature, 75%; (ii) $SnCl_2$, AgOTf, DTBMP, DCE, 4 Å molecular sieves, 50 °C, 54%.

A selection of aglycons, including mono- **7**,[19] **22**,[23] di- **20**[24] and trisaccharide **21**[25] alcohols, were used as coupling partners, and using the I_2, AgOTf, DTBMP reagent combination produced good yields of mixed acetals **23**, **26**, **24** and **25**, respectively (Table 1).

Besides the marked improvement of reaction yields, a further advantage of the I_2/AgOTf/DTBMP system over alternative sources of I^+ was demonstrated by the quantity of reagents needed for complete reaction. In previous studies, typically 3 equiv of the I^+ source (e.g., NIS), and a 2- to 3-fold excess of the aglycon alcohol were required in order to obtain satisfactory tethering



Scheme 2. Reagents and conditions: (i) TolSH, DCE, reflux, 65%; (ii) Na, MeOH; (iii) allyl bromide, NaH, DMF, 95% over two steps; (iv) $(Ph_3P)_3RhCl$, *n*-BuLi, THF, reflux, 94%; (v) Na, MeOH; (vi) $PhCH(OMe)_2$, camphor sulfonic acid, DMF, 38% over two steps; (vii) PivCl, pyridine, 0 °C, 76%; (viii) allyl bromide, NaH, DMF, 74%; (ix) $(Ph_3P)_3RhCl$, *n*-BuLi, THF, reflux, 95%.

yields. In contrast, with the I_2/AgOTf/DTBMP reagent combination, only virtually equimolar quantities of enol ether and aglycon alcohol were required to give good yields of the mixed acetals. This represents an important advantage, particularly in the cases of more precious aglycon alcohols, such as di- or trisaccharides.

2.2. Mechanistic investigations

2.2.1. Tethering reactions. In certain cases, integration of the carbohydrate H-1 signals in the ^1H NMR spectra of the mixed acetals obtained by treatment of an allyl derived 2-*O*-vinyl ether with an iodonium ion source and an aglycon alcohol allows measurement of the diastereomeric ratios of the mixed acetal products. Moreover, correlation of these values with the *Z*:*E* diastereomeric ratios of the vinyl ether starting materials gives an insight into the precise mechanism of the tethering reaction. For example, an *N*-iodosuccinimide mediated tethering reaction of methanol to the *rhamno* vinyl ethers **27***E*/*Z*,[26] gave the mixed acetals **28a**–**d**.[26] Assignment of each diastereomer was arbitrarily based on the chemical shift of H-1, given in brackets (Table 2). The product distribution of the four diastereomeric mixed acetals varied with the ratio of *Z*- and *E*-vinyl ether starting materials as detailed in Table 2. Two points are worthy of note. First, in this particular case,

Table 1. Synthesis of mixed acetals mediated by I_2, AgOTf and DTBMP

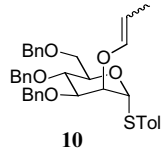
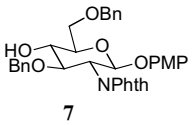
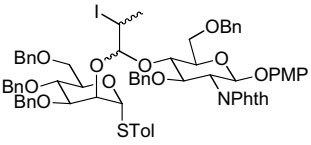
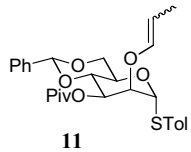
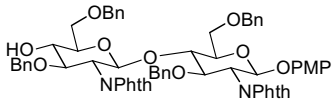
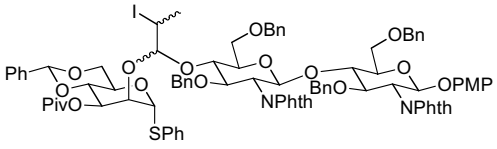
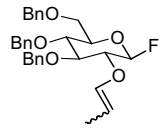
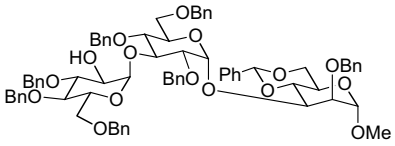
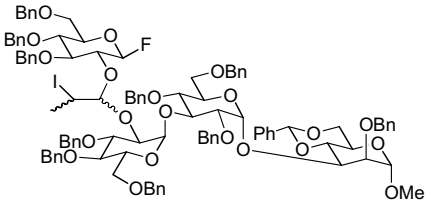
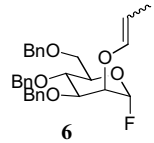
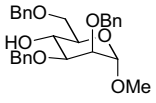
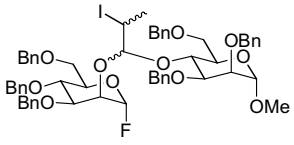
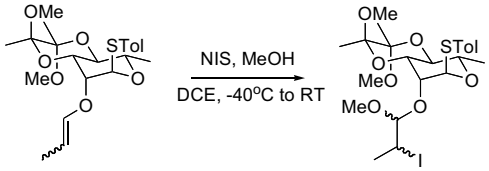
Enol ethers	Aglycon	Mixed acetals	Yield (%)
 **10**	 **7**	 **23**	77
 **11**	 **20**	 **24**	75
 **12**	 **21**	 **25**	78
 **6**	 **22**	 **26**	55

Table 2. Variation of diastereomeric ratios of mixed acetals formed with vinyl ether configuration



27*E*/*Z* **28a-d**

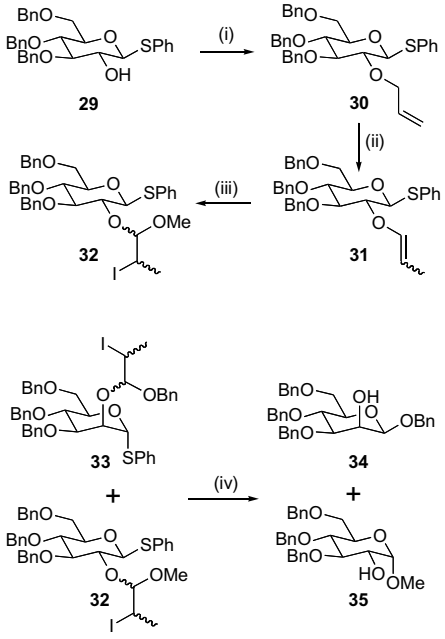
Entry	**27*E*/*Z***	**28a** (5.46)[a]	**28b** (5.43)[a]	**28c** (5.41)[a]	**28d** (5.36)[a]
1	33:67	6	17	60	17
2	68:32	17	8	25	50
3	0:100	3	23	71	3
4	100:0	22	4	4	70

[a] Chemical shift of H-1 of each diastereomer given in brackets.

all four diastereomeric products were formed in all four cases, even when either pure *Z*- or pure *E*-vinyl ether was used as a starting material. Secondly the diastereomeric ratio of products is strongly dependent on the ratio of vinyl ethers used: the use of pure *Z*-vinyl ether **27*Z*** as staring material resulted in the formation of predominantly **28b** and **28c**, whereas the use of pure *E*-vinyl ether **27*E*** resulted in the formation of predominantly **28a** and **28d**. These two points taken together suggest that a cyclic iodonium ion mechanism may predominate in this case, but there is some degree of leakage, which allows the formation of small amounts of diastereomeric products which can only arise from a non-bridged intermediate wherein C–C bond rotation occurs before nucleophilic trapping by the algycon alcohol. In other cases, particularly with more hindered aglycon alcohols, the diastereomeric ratio of the mixed acetals was observed to vary markedly depending on the identity of the algycon alcohol, presumably indicating reversibility of iodination and the intermediacy of non-bridged intermediates.

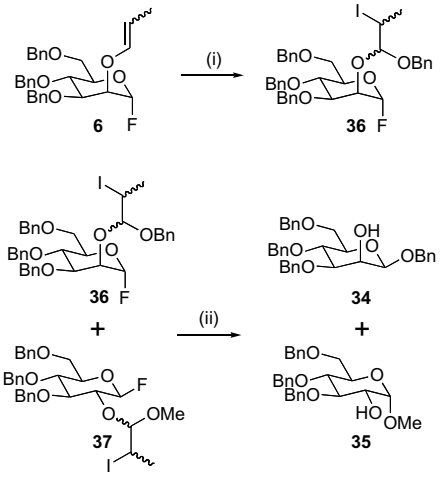
2.2.2. Glycosylation reactions. The question as to whether the glycosylation step of allyl IAD, which follows on from activation of the anomeric leaving group of mixed acetals such as **1**, is entirely intramolecular or is not an important one. Previous studies of competition reactions of allyl-derived mixed acetals **1** in the presence of added external nucleophiles, such as methanol, have revealed that intermolecular glycosylation does compete with glycosylation of the tethered aglycon in the allyl system. Here, a diastereomeric mixture of methyl glycosides arising from a nonstereoselective intermolecular glycosylation reaction was produced as well as the desired 1,2-*cis* glycoside product.[12b] This result was in contrast to earlier studies on the Hindsgaul IAD system, in which internal delivery of the tethered nucleophile competed over

any intermolecular process.[5a,10] Although the formation of only the 1,2-*cis* glycoside in any of the glycosylation reactions previously performed in the allyl IAD system implied that glycosylation was entirely intramolecular, a more definitive investigation involving crossover reactions was undertaken. Such crossover reactions have previously revealed the intermolecular nature of a series of glycosylation reactions that were initially thought to be intramolecular,[27] though the lack of total stereocontrol in these latter reactions also pointed to non-intramolecularity. To this end, two crossover reactions were designed. The first required the synthesis of the *gluco* mixed acetal **32** derived from reaction of enol ethers **31** with methanol (Scheme 3). Enol ethers **31** were themselves accessed from the known alcohol **29**[28] by a sequence of allylation, to give allyl ether **30** and then Wilkinson's catalyst mediated allyl isomerisation, which led to enol ethers **31**. NIS-mediated mixed acetal formation with methanol then resulted in the formation of the required mixed acetal **32**. Glycosylation of an equimolar mixture of this mixed acetal **32** and the known benzyl *manno* mixed acetal **33**[12b] produced only the β-*manno* benzyl glycoside **34** and the α-*gluco* methyl glycoside **35** (Scheme 3). No crossover products, that is, benzyl glucosides or methyl mannosides, were produced in detectable amounts during this reaction.



Scheme 3. Reagents and conditions: (i) allyl bromide, NaH, DMF, 75%; (ii) $(Ph_3P)_3RhCl$, *n*-BuLi, THF, reflux, 96%; (iii) MeOH, NIS, 4 Å molecular sieves, DCE, −78 °C to room temperature, 96%; (iv) NIS, AgOTf, DTBMP, 4 Å molecular sieves, DCE, 50 °C; **32**, 56%; **33**, 52%.

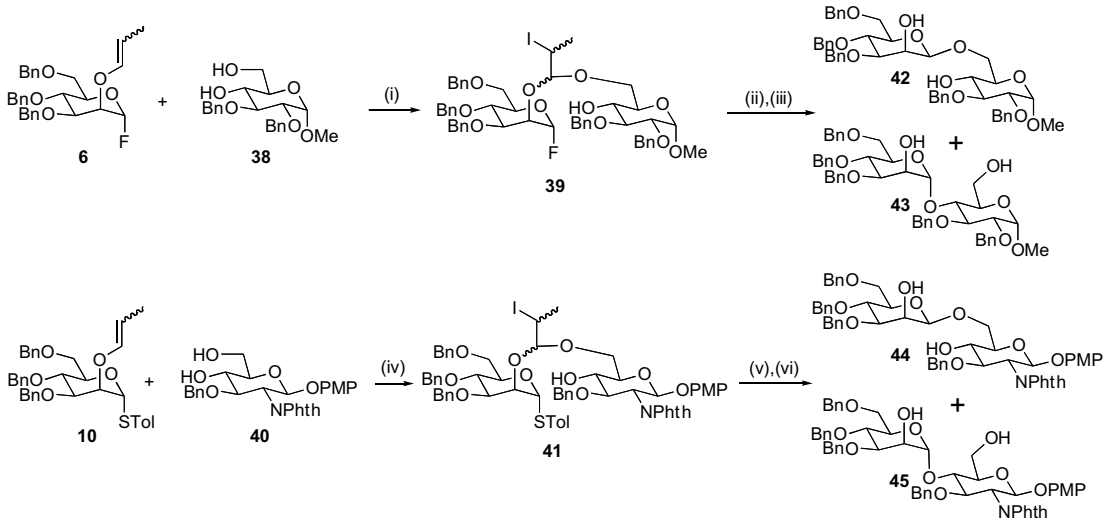
Since the activation conditions for glycosyl fluorides are markedly different to those used for thioglycoside activation, a similar crossover reaction was undertaken for glycosyl fluoride donors. In particular, in this case, Lewis acid catalysed scrambling of mixed acetal starting materials was considered to be a potential side reaction that could also lead to the formation of crossover products. Benzyl *manno* mixed acetal **36** was synthesised from enol ethers **6** by treatment with NIS and benzyl alcohol (Scheme 4). A similar mixed glycosylation reaction of this *manno* mixed acetal **36** and known *gluco* mixed acetal **37**,[13] mediated by tin(II) chloride and AgOTf in the presence of DTBMP, again produced only the β-*manno* benzyl glycoside **34** and the α-*gluco* methyl glycoside **35** (Scheme 4). No crossover products were observed. These results strongly indicate that, at least in the cases of thioglycosides and glycosyl fluorides, the glycosylation reaction step of allyl IAD is almost certainly entirely intramolecular in nature.



Scheme 4. Reagents and conditions: (i) BnOH, NIS, 4 Å molecular sieves, DCE, −40 °C to room temperature, 88%; (ii) $SnCl_2$, AgOTf, DTBMP, 4 Å molecular sieves, DCE, 50 °C; **32**, 60%; **33**, 59%.

2.3. Attempted synthesis of β-1,4-linked disaccharides

The efficiency of the formation of mixed acetals in the first tethering step of the IAD process is dependent on the steric bulk of the aglycon alcohol. In particular, the 4-hydroxyl of a carbohydrate aglycon is generally the most hindered and therefore the most difficult to glycosylate. Indeed, previous experience indicated that tethering reactions of the 4-hydroxyl of carbohydrate aglycons were consistently less efficient than for the other hydroxyl groups, hence the choice of aglycon **7** as a worst case scenario (vide supra). In an attempt to circumvent this problem, it was envisaged that the steric differentiation between the 4-hydroxyl and the primary 6-hydroxyl of a hexose glycosyl acceptor could in fact be used advantageously in the allyl IAD approach. The principle was that selective tethering of a glycosyl acceptor, in which both the 4- and 6-hydroxyls were unprotected, would occur regioselectively through the less hindered primary hydroxyl, leaving the 4-hydroxyl free to participate in the subsequent intramolecular glycosylation reaction. This intramolecular glycosylation reaction would be similar in nature to the approaches previously published by Shiba and co-workers,[29] Schmidt and co-workers,[30] Ziegler and co-workers,[31] Fukase and co-workers,[32] Takahsahi and co-workers[33] and Valverde and co-workers.[34]



Scheme 5. Reagents and conditions: (i) NIS, 4 Å molecular sieves, DCE, −40 °C to room temperature, 73%; (ii) $SnCl_2$, AgOTf, DTBMP, 4 Å molecular sieves, DCE, 50 °C; (iii) THF, TFA, MeOH, H_2O; **41**, 12% over two steps; **40**, 29% over two steps; (iv) NIS, 4 Å molecular sieves, DCE, −78 °C to room temperature, 60%; (v) NIS, AgOTf, DTBMP, 4 Å molecular sieves, DCE, 50 °C; (vi) THF, TFA, MeOH, H_2O; **42**, 16% over two steps; **43**, 30% over two steps.

In order to investigate the feasibility of such an approach, the known diol **38**[35] and enol ethers **6** were tethered selectively through the 6-hydroxyl of **38** by treatment with NIS in DCE at low temperature, to give the mixed acetals **39** (Scheme 5). However, subsequent intramolecular glycosylation of mixed acetals **37** did not produce the expected β(1→4) linked products. Glycosylation of **39**, mediated by tin(II) chloride and AgOTf in the presence of DTBMP, produced a mixture of tricyclic products, which were then treated with a mixture of trifluoroacetic acid/methanol/THF/water (5:2:2:1) to yield the β(1→6) linked disaccharide **42**[6b] and the α(1→4) linked disaccharide **43** as the major reaction products. None of the hoped for β(1→4) linked product was observed.

To corroborate this unexpected result, a similar investigation was undertaken with thioglycoside donors Thus, reaction of enol ethers **10** and the known diol **40**,[36] again mediated by NIS, produced mixed acetal **41**, in which tethering had again selectively occurred through the primary hydroxyl group of **38**. However subsequent glycosylation, on this occasion mediated by NIS and AgOTf in DCE, again produced a complex mixture of tricyclic products, which were then treated directly with trifluoroacetic acid/methanol/THF/water (5:2:2:1) to yield the β(1→6) linked disaccharide **44** and the α(1→4) linked disaccharide **45** as the major reaction products. Again, none of the anticipated β(1→4) linked product was observed (Scheme 5).

The failure of these two glycosylation reactions to give the desired β(1→4) product highlights two potential problems when designing an intramolecular glycosylation strategy. Firstly, it is clear that the use of a longer tether can lead to the formation of the undesired anomer of the product, as demonstrated by the formation of the α(1→4) linked products **43** and **45**. This implies that longer tethers may lead to rather unpredictable and therefore less useful results. Secondly, in the mixed acetal IAD approach, the formation of the β(1→6) linked products **42** and **44** demonstrates that free hydroxyl groups are not necessarily glycosylated in preference to those involved in forming the tether. These observations taken together strengthen the case for the development of an intramolecular glycosylation strategy based on as short a tether as possible, and one in which the hydroxyl of the acetal is the one that is delivered in the intramolecular glycosylation reaction.

3. Conclusions

Allyl IAD is a useful technique that allows the synthesis of a variety of 1,2-*cis* glycosides and disaccharides with complete stereocontrol. The optimisation of the first step of mixed acetal formation, using the I_2, AgOTf and DTBMP reagent combination, represents a significant improvement over previous procedures, and now permits the formation of mixed acetals derived from secondary alcohols of mono-, di- and trisaccharides in high yield, importantly, using only 1 equiv of all reagents. Crossover glycosylation reactions provide substantial supporting evidence that the glycosylation step of allyl IAD is indeed entirely intramolecular in nature for both thioglycosides and glycosyl fluorides. Finally, the failure of the attempted synthesis of β(1→4) disaccharides highlights the potential problems of regio- and stereoselectivity inherent in an intramolecular glycosylation strategy in which the donor and acceptor, which themselves possess a free hydroxyl group, are linked by a longer mixed acetal tether. Glycosylation of the free hydroxyl of the acceptor may not necessarily occur in preference to the hydroxyl forming the mixed acetal, and the use of a longer tether may result in loss of the desired 1,2-*cis* stereocontrol. Further investigations into the develop-

ment of allyl IAD for the stereospecific synthesis of a variety of oligosaccharides containing 1,2-*cis* linkages are currently in progress and the results will be reported in due course.

4. Experimental

4.1. General

Melting points were recorded on a Kofler hot block. Proton nuclear magnetic resonance (δ_H) spectra were recorded on Varian Gemini 200 (200 MHz), Bruker AC 200 (200 MHz), Bruker DPX 400 (400 MHz), Bruker AV 400 (400 MHz), or Bruker AMX 500 (500 MHz) spectrometers. Carbon nuclear magnetic resonance (δ_C) spectra were recorded on a Bruker DPX 400 (100.6 MHz) or a Bruker AMX 500 (125.75 MHz) spectrometer. Multiplicities were assigned using APT or DEPT sequence. All chemical shifts are quoted on the δ scale. Infrared spectra were recorded on a Perkin–Elmer 150 Fourier Transform spectrophotometer. Mass spectra were recorded on VG Micromass 30F, ZAB 1F, Masslab20-250, Micromass Platform 1 APCI or Trio-1 GCMS (DB-5 column) spectrometers, using desorption chemical ionisation (NH_3 DCI), electron impact (EI), electron spray ionisation (ESI), chemical ionisation (NH_3 CI), atmospheric pressure chemical ionisation (APCI) and fast atom bombardment (FAB) techniques as stated. Optical rotations were measured on a Perkin–Elmer 241 polarimeter with a path length of 1 dm. Concentrations are given in g/100 mL. Microanalyses were performed by the microanalytical services of the Inorganic Chemistry Laboratory, Oxford. Thin layer chromatography (TLC) was carried out on Merck glass backed sheets, pre-coated coated with $60F_{254}$ silica. Plates were developed using 0.2% w/v cerium(IV) sulfate and 5% ammonium molybdate in 2 M sulfuric acid. Flash chromatography was carried out using Sorbsil C60 40/60 silica. Solvents and available reagents were dried and purified before use according to standard procedures; dichloromethane was distilled from calcium hydride immediately before use.

4.2. General procedure A: tethering with I_2, AgOTf and DTBMP

Iodine (55 mg, 0.22 mmol), silver triflate (56 mg, 0.22 mmol), 2,6-di-*tert*-butyl-4-methylpyridine (116 mg, 0.57 mmol) and 4 Å molecular sieves were added to freshly distilled CH_2Cl_2 (1 mL) and cooled to −78 °C under Ar. The aglycon alcohol (65 mg, 0.18 mmol) was dissolved in freshly distilled CH_2Cl_2 (2 mL) and added by cannula under Ar. The enol ethers (100 mg, 0.17 mmol) were dissolved in freshly distilled CH_2Cl_2 (2 mL) and added to the reaction vessel by cannula under Ar. The reaction was allowed to warm to room temperature. After 17 h, the reaction was quenched with sodium thiosulfate (40 mL of a 10% aqueous solution) and then extracted with CH_2Cl_2 (2 × 40 mL). The combined organic extracts were dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was purified by flash column chromatography (petrol–ethyl acetate, 7:1 → 3:1) to afford the mixed acetals as a colourless oil.

4.3. 3,4,6-Tri-*O*-benzyl-2-*O*-(2-iodo-1-(*para*-methoxyphenyl 3,6-di-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosid-4-*O*-yl)propyl)-α-D-mannopyranosyl fluoride 8

General procedure A: Alcohol **7** (102 mg, 0.17 mmol) and enol ethers **6** (80 mg, 0.16 mmol) gave mixed acetals **8** (147 mg, 75%) as a colourless oil; *m/z* (ES^+) 1252 ($M + K^+$, 7), 1236 ($M + Na^+$, 100), 1231 ($M + NH_4^+$, 41).

4.4. *para*-Methoxyphenyl 3,4,6-tri-*O*-benzyl-β-D-mannopyranosyl-(1→4)-3,6-di-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranoside 9

Molecular sieves (4 Å) were suspended in anhydrous dichloroethane (1 mL) in a flame-dried flask under Ar. 2,6-Di-*tert*-butyl-4-methylpyridine (50 mg, 0.25 mmol), silver trifluoromethanesulfonate (63 mg, 0.25 mmol) and anhydrous tin(II) chloride (47 mg, 0.25 mmol) were added. Mixed acetals **8** (147 mg, 0.12 mmol) were dissolved in anhydrous dichloroethane (6 mL) and added by cannula under Ar. The reaction mixture was stirred at 50 °C. After 7.5 h, TLC (petrol–ethyl acetate, 3:1) indicated the absence of any starting material (R_f 0.5) and the formation of a major (R_f 0.1) and minor (R_f 0.2) product. The reaction was quenched with $NaHCO_3$ (15 mL of a saturated aqueous solution) and the mixture stirred for a further 20 min. The mixture was diluted with ethyl acetate (150 mL), filtered through Celite and washed with brine (50 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was purified by flash column chromatography (petrol–ethyl acetate, 3:1 → 1:1) to afford β-*manno* disaccharide **9** (67 mg, 54%) as a colourless oil; $[\alpha]_D^{25} = +44.5$ (*c* 1.5, $CHCl_3$) [lit. +52 (*c* 0.59, $CHCl_3$)];[12b] δ_H (400 MHz, $CDCl_3$) 3.35 (1H, ddd, $J_{4,5}$ 9.6 Hz, $J_{5,6}$ 4.5 Hz, $J_{5,6'}$ 1.4 Hz, H-5_b), 3.44 (1H, dd, $J_{2,3}$ 3.3 Hz, $J_{3,4}$ 9.2 Hz, H-3_b), 3.64 (1H, dd, $J_{6,6'}$ 10.7 Hz, H-6_b), 3.72 (3H, s, OCH_3), 3.74–3.77 (2H, m, H-5_a, H-$6'_b$), 3.79 (1H, dd, $J_{5,6}$ 1.9 Hz, $J_{6,6'}$ 11.2 Hz, H-6_a), 3.84 (1H, dd, $J_{5,6'}$ 3.9 Hz, H-$6'_a$), 3.87 (1H, at, *J* 9.2 Hz, H-4_b), 4.05 (1H, d, H-2_b), 4.18 (1H, at, *J* 8.6 Hz, H-3_a), 4.42–4.47 (2H, m, H-2_a, H-4_a), 4.48 (2H, s, PhCH_2), 4.52, 4.69 (2H, ABq, J_{AB} 12.0 Hz, PhCH_2), 4.54, 4.86 (2H, ABq, J_{AB} 10.8 Hz, PhCH_2), 4.55, 4.94 (2H, ABq, J_{AB} 12.4 Hz, PhCH_2), 4.56, 4.64 (2H, ABq, J_{AB} 11.8 Hz, PhCH_2), 4.70 (1H, s, H-1_b), 5.63 (1H, d, $J_{1,2}$ 7.9 Hz, H-1_a), 6.69–6.73 (2H, m, Ar-H), 6.79–6.85 (4H, m, Ar-H), 7.01–7.03 (2H, m, Ar-H), 7.19–7.63 (21H, m, Ar-H), 7.68–7.80 (4H, m, Ar-H); δ_C (125.7 MHz, $CDCl_3$) 55.4, 55.6 (d, q, C-2_a, OCH_3), 67.9 (d, C-2_b), 68.4, 68.8 (2 × t, C-6_a, C-6_b), 71.2, 73.2, 73.4, 74.7, 75.0 (5 × t, 5 × PhCH_2), 73.8 (d, C-4_b), 74.6 (d, C-5_a), 75.4 (d, C-5_b), 77.8, 78.0 (2 × d, C-3_a, C-4_a), 81.6 (d, C-3_b), 97.6 (d, $^1J_{C\text{-}1,H\text{-}1}$ 166.0 Hz, C-1_a), 100.3 (d, $^1J_{C\text{-}1,H\text{-}1}$ 158.1 Hz, C-1_b), 114.2, 118.7, 123.2, 126.9, 127.3, 127.5, 127.6, 127.7, 127.7, 127.7, 127.8, 127.8, 127.9, 128.0, 128.2, 128.2, 128.4, 128.4, 128.4, 133.6 (20 × d, Ar-CH), 137.8, 138.1, 138.2, 138.3, 150.7, 155.3 (6 × s, Ar-C).

4.5. *para*-Tolyl 2-*O*-acetyl-3,4,6-tri-*O*-benzyl-1-thio-α-D-mannopyranoside 14

Orthoester **13**[21] (2.0 g, 3.85 mmol) and *para*-thiocresol (717 mg, 5.78 mmol) were dissolved in DCE (20 mL) and the solution heated to reflux under argon. After 72 h, TLC (petrol–ethyl acetate, 3:1) indicated no remaining starting material (R_f 0.35) and the formation of a major product (R_f 0.45). The reaction mixture was allowed to cool to room temperature and then concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 5:1) gave thioglycoside **14** as a white solid (1.87 g, 65%), which was recrystallised from ethyl acetate/petrol; mp 78–79 °C; $[\alpha]_D^{25} = +125$ (*c* 1.08, $CHCl_3$); ν_{max} (KBr) 1750 (C=O) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 2.17 (3H, s, CO_2CH_3), 2.33 (3H, s, $ArCH_3$), 3.75 (1H, dd, $J_{5,6}$ 2.0 Hz, $J_{6,6'}$ 11.0 Hz, H-6), 3.88 (1H, dd, $J_{5,6'}$ 4.5 Hz, H-6′), 3.96–4.01 (2H, m, H-3, H-4), 4.37 (1H, ddd, $J_{4,5}$ 9.0 Hz, H-5), 4.49, 4.69 (2H, ABq, J_{AB} 12.0 Hz, $PhCH_2$), 4.53, 4.91 (2H, ABq, J_{AB} 10.5 Hz, $PhCH_2$), 4.59, 4.75 (2H, ABq, J_{AB} 11.0 Hz, $PhCH_2$), 5.49 (1H, d, $J_{1,2}$ 1.5 Hz, H-1), 5.63 (1H, dd, $J_{2,3}$ 2.0 Hz, H-2), 7.07–7.09 (2H, m, 2 × Ar-H), 7.20–7.40 (17H, m, 17 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.1 (q, CO_2CH_3, $ArCH_3$), 68.8, 71.9, 73.3, 75.3 (4 × t, C-6, 3 × $PhCH_2$), 70.3, 72.4, 74.5, 78.5, 86.5 (5 × d, C-1, C-2, C-3, C-4, C-5), 127.6, 127.7, 127.8, 127.9, 128.2, 128.3, 128.4, 128.5, 129.8, 132.3 (10 × d, Ar-CH), 137.6, 137.9, 138.2, 138.3 (4 × s, Ar-C), 170.4 (d, C=O); *m*/*z* (ES^+) 622 (39), 621 ($M + Na^+$, 100), 616 ($M + NH_4^+$, 40); (HRMS (ES^+) Calcd for $C_{36}H_{38}O_6SNa$ (MNa^+) 621.2287. Found 621.2288). (Found: C, 72.23; H, 6.37. $C_{36}H_{38}O_6S$ requires: C, 72.22; H, 6.40).

4.6. *para*-Tolyl 2-*O*-allyl-3,4,6-tri-*O*-benzyl-1-thio-α-D-mannopyranoside 15

Acetate **14** 1.626 g, 2.7 mmol) was dissolved in methanol (40 mL) and a solution of sodium (53 mg, 2.3 mmol) in methanol (1 mL) added. The reaction mixture was stirred at room temperature for 3 h, after which time, TLC (petrol–ethyl acetate, 3:1) showed no remaining starting material (R_f 0.85) and the formation of a single product (R_f 0.45). The reaction mixture was co-evaporated with toluene and subsequently exposed to high vacuum for 2 h. The resulting residue was taken up in DMF (25 mL) and allyl bromide (0.58 mL, 6.7 mmol) added, followed by sodium hydride (60% dispersion in mineral oil, 324 mg, 8.1 mmol). This solution was stirred for 3 h, after which time TLC (petrol–ethyl acetate, 3:1) showed no remaining starting material (R_f 0.5) and the formation of a major product (R_f 0.7). Methanol (5 mL) was added slowly and the mixture concentrated in vacuo (at 60 °C). The residue was taken up in ether (200 mL) and washed with brine (2 × 100 mL). The aqueous layers were re-extracted with ether (100 mL) and the combined organic extracts dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ether, 4:1) gave allyl ether **15** (1.536 g, 95%) as a clear oil; $[\alpha]_D^{25} = +137.1$ (*c* 0.96, $CHCl_3$); ν_{max} (thin film) 1645 (w, C=C) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 2.32 (3H, s, CH_3), 3.75 (1H, dd, $J_{5,6}$ 1.5 Hz, $J_{6,6'}$ 11.0 Hz, H-6), 3.84 (1H, dd, $J_{5,6'}$ 5.0 Hz, H-6′), 3.88 (1H, dd, $J_{2,3}$ 3.0 Hz, $J_{3,4}$ 9.5 Hz, H-3), 3.96 (1H, d, H-2), 4.01 (1H, at, *J* 9.5 Hz, H-4), 4.10 (1H, dd, J_{gem} 13.0 Hz, *J* 6.0 Hz, $CHH'CH{=}CH_2$), 4.19 (1H, dd, *J* 5.5 Hz, $CHH'CH{=}CH_2$), 4.30 (1H, ddd, H-5), 4.48, 4.65 (2H, ABq, J_{AB} 12.0 Hz, $PhCH_2$), 4.53, 4.92 (2H, ABq, J_{AB} 11.0 Hz, $PhCH_2$), 4.70, 4.74 (2H, ABq, J_{AB} 12.0 Hz, $PhCH_2$), 5.20 (1H, d, J_Z 10.5 Hz, $CH{=}CH_EH_Z$), 5.31 (1H, d, J_E 17.0 Hz, $CH{=}CH_EH_Z$), 5.53 (1H, s, H-1), 5.88–5.98 (1H, m, $CH{=}CH_2$), 7.05–7.07 (2H, m, 2 × Ar-H), 7.21–7.42 (17H, m, 17 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.0 (q, $ArCH_3$), 69.2, 71.3, 72.2, 73.2, 75.2 (5 × t, C-6, 3 × $PhCH_2$, $CH_2CH{=}CH_2$), 75.6, 75.0, 76.1, 76.7 (4 × d, C-2, C-3, C-4, C-5), 86.0 (d, C-1), 117.9 (t, $CH{=}CH_2$), 127.4, 127.6, 127.8, 127.9, 128.0, 128.2, 128.3, 128.4, 129.7, 132.0 (10 × d, Ar-CH), 130.6, 137.5, 138.1, 138.3, 138.4 (5 × s, Ar-C), 134.6 (d, $CH{=}CH_2$); *m*/*z* (ES^+) 620 (37), 619 ($M + Na^+$, 100), 615 (36), 614 ($M + NH_4^+$, 93); (HRMS (ES^+) Calcd for $C_{37}H_{40}O_5SNa$ (MNa^+) 619.2494. Found 619.2485). (Found: C, 74.76; H, 6.66. $C_{37}H_{40}O_5S$ requires: C, 74.47; H, 6.76).

4.7. *para*-Tolyl 3,4,6-tri-*O*-benzyl-2-*O*-(prop-1-enyl)-1-thio-α-D-mannopyranoside 10

n-Butyllithium (1.6 M in hexanes, 193 μL) was added to a degassed solution of Wilkinson's catalyst (162 mg, 0.18 mmol) in tetrahydrofuran (7 mL). This mixture was stirred for 10 min before being added to a refluxing solution of allyl ether **15** (1.024 g, 1.72 mmol) in tetrahydrofuran (6 mL). After 10 min, TLC (petrol–ethyl acetate, 5:1) showed no remaining starting material (R_f 0.5) and the formation of a single product (R_f 0.6). The solution was allowed to cool to room temperature before the addition of dichloromethane (50 mL) and concentration in vacuo. Purification by flash column chromatography (petrol–ether, 7:1, with 1% added triethylamine) gave enol ethers **10**, a clear, colourless oil, as a partially separable mixture of *E*- and *Z*-isomers (959 mg, 94%); ν_{max} (thin film) 1668 (m, C=C) cm^{-1}; NMR data for *E*-isomer: δ_H (400 MHz, $CDCl_3$) 1.54 (3H, dd, *J* 1.5 Hz, *J* 7.0 Hz, $CHCH_3$), 2.31 (3H, s, $ArCH_3$), 3.75 (1H, dd, $J_{5,6}$ 2.0 Hz, $J_{6,6'}$ 11.0 Hz, H-6), 3.84 (1H, dd, $J_{5,6'}$ 5.0 Hz, H-6′), 3.91 (1H, dd, $J_{2,3}$ 3.0 Hz, $J_{3,4}$ 9.5 Hz, H-3), 4.02 (1H, at, *J* 9.5 Hz, H-4), 4.20 (1H, d, $J_{1,2}$ 1.5 Hz, H-2), 4.31 (1H, ddd, H-5), 4.48, 4.65 (2H, ABq, J_{AB} 12.0 Hz, $PhCH_2$), 4.54 (1H, d, *J* 11.0 Hz, $PhCHH'$), 4.72 (2H, s, $PhCH_2$), 4.90–4.98 (2H, m, $PhCHH'$, CH_3CH), 5.54 (1H, d, H-1), 6.08 (1H, dd, *J* 12.5 Hz, $OCH{=}CH$), 7.05–7.07 (2H, m, 2 × Ar-H), 7.21–7.42 (17H, m, 17 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 12.4 (q, $CHCH_3$), 21.1 (q, $ArCH_3$), 69.1, 72.2, 73.3, 75.3 (4 × t, C-6, 3 × $PhCH_2$), 72.5, 74.8, 76.7, 79.2, (4 × d, C-2, C-3, C-4, C-5), 85.4 (d, C-1), 102.5 (d, $CHCH_3$), 127.4, 127.5, 127.6, 127.7, 127.8, 128.0, 128.0, 128.0, 128.1, 128.2, 128.2, 128.3, 128.5, 129.5, 132.0, 132.3, (16 × d, Ar-CH), 130.2, 137.6, 137.9, 138.3, 138.4 (5 × s, Ar-C), 144.8 (d, $OCH{=}CH$); NMR data for *Z*-isomer: δ_H (400 MHz, $CDCl_3$) 1.67 (3H, dd, *J* 1.5 Hz, *J* 7.0 Hz, $CHCH_3$), 2.32 (3H, s, $ArCH_3$), 3.79 (1H, dd, $J_{5,6}$ 2.0 Hz, $J_{6,6'}$ 11.0 Hz, H-6), 3.88 (1H, dd, $J_{5,6'}$ 5.0 Hz, H-6′), 3.94 (1H, dd, $J_{2,3}$ 3.0 Hz, $J_{3,4}$ 9.5 Hz, H-

3), 4.10 (1H, at, J 9.5 Hz, H-4), 4.12 (1H, d, $J_{1,2}$ 2.0 Hz, H-2), 4.34 (1H, ddd, H-5), 4.51, 4.67 (2H, ABq, J_{AB} 12.0 Hz, PhCH_2), 4.55–4.61 (1H, m, CHCH$_3$), 4.58, 4.94 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 4.76 (2H, s, PhCH_2), 5.47 (1H, d, H-1), 5.90–5.92 (1H, m, OCH=CH), 7.06–7.08 (2H, m, 2 × Ar-H), 7.24–7.44 (17H, m, 17 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 9.6 (q, CH$_3$), 21.1 (q, ArCH$_3$), 69.1, 72.3, 73.2, 75.3 (4 × t, C-6, 3 × PhCH$_2$), 72.7 (d, C-5), 74.9, 78.8 (2 × d, C-2, C-4), 79.5 (d, C-3), 86.5 (d, C-1), 105.0 (d, CHCH$_3$), 127.4, 127.6, 127.7, 127.9, 128.0, 128.0, 128.2, 128.4, 128.5, 129.8, 132.3 (11 × d, Ar-CH), 137.8, 138.0, 138.4, 138.4 (4 × s, Ar-C), 143.9 (d, OCH=CH); m/z (ES^+) 620 (37), 619 (M + Na^+, 100), 614 (M + NH_4^+, 70). (HRMS (ES^+) Calcd for $C_{37}H_{40}NaO_5S$ (MNa^+) 619.2494. Found 619.2491). (Found: C, 74.54; H, 6.75. $C_{37}H_{40}O_5S$ requires: C, 74.47; H, 6.76).

4.8. *para*-Tolyl (*R*)-4,6-*O*-benzylidene-1-thio-α-D-mannopyranoside 17

Tetraacetate **16**[22] (8.39 g, 18.4 mmol) was dissolved in methanol (140 mL) and a solution of sodium (40 mg, 1.7 mmol) in methanol (2 mL) added. The reaction mixture was stirred at room temperature for 3 h, after which time, TLC (petrol–ethyl acetate, 1:4) showed no remaining starting material (R_f 0.8) and the formation of a single product (R_f 0.0). A small quantity of Dowex® 50WX8 acidic ion exchange resin was added, and after 30 min, the solution became pH neutral. The ion exchange resin was removed by filtration and the reaction mixture co-evaporated twice with toluene and subsequently exposed to high vacuum for 2 h. This crude intermediate was dissolved in DMF (60 mL) and benzaldehyde dimethyl acetal (3 mL, 20.0 mmol) and camphor sulfonic acid (128 mg, 0.6 mmol) added. The reaction mixture was subjected to reduced pressure (ca. 10 mbar) at room temperature on a rotary evaporator for 5 h, after which time additional benzaldehyde dimethyl acetal (0.5 mL, 3.3 mmol) was added. After a further 4 h under reduced pressure, TLC (ethyl acetate) showed little remaining starting material (R_f 0.05) and the formation of a major product (R_f 0.70). Triethylamine (5 mL) and then ethyl acetate (400 mL) were added and the mixture washed with brine (3 × 150 mL). The aqueous washes were re-extracted with ethyl acetate (150 mL), and the combined organic extracts dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 1:1 → 0:1) gave diol **17** as a white powder (2.41 g, 38% over two steps); mp 206–208 °C (ethyl acetate); $[\alpha]_D^{25} = +201.7$ (c 0.58, Me_2SO); ν_{max} (KBr) 3226 (br, OH) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 2.35 (3H, s, CH_3), 2.70 (1H, d, $J_{3,OH}$ 3.5 Hz, OH-3), 2.79 (1H, d, $J_{2,OH}$ 2.0 Hz, OH-2), 3.84 (1H, at, $J_{5,6} = J_{6,6'}$ 10.5 Hz, H-6), 4.01 (1H, at, $J_{3,4} = J_{4,5}$ 9.5 Hz, H-4), 4.13–4.17 (1H, m, H-3), 4.24 (1H, dd, $J_{5,6'}$ 5.0 Hz, H-6′), 4.32–4.33 (1H, m, H-2), 4.37 (1H, ddd, H-5), 5.53 (1H, s, H-1), 5.59 (1H, s, PhCH), 7.14–7.16 (2H, m, 2 × Ar-H), 7.36–7.43 (5H, m, 5 × Ar-H), 7.50–7.55 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.1 (q, CH$_3$), 64.1, 69.1 (2 × d, C-3, C-5), 68.5 (t, C-6), 72.2 (d, C-2), 79.0 (d, C-4), 88.3 (d, C-1), 102.3 (d, PhCH), 126.3, 128.4, 129.3, 130.0, 132.4 (5 × d, Ar-CH), 137.1, 138.1 (2 × s, Ar-C); m/z (ES^+) 398 (21), 397 (M + Na^+, 100), 375 (M + H^+, 44). (HRMS (ES^+) Calcd for $C_{20}H_{22}NaO_5S$ (MNa^+) 397.1086. Found 397.1090). (Found: C, 64.01; H, 5.92. $C_{20}H_{22}O_5S$ requires: C, 64.15; H, 5.92).

4.9. *para*-Tolyl (*R*)-4,6-*O*-benzylidene-3-*O*-pivaloyl-1-thio-α-D-mannopyranoside 18

Diol **17** (673 mg, 1.8 mmol) was dissolved in pyridine (10 mL) and cooled to 0 °C. Pivaloyl chloride (0.32 mL, 2.6 mmol) was then added dropwise. After stirring for an hour, additional pivaloyl chloride (0.12 mL, 1 mmol) was added. After a further 1 h, TLC (petrol–ethyl acetate, 1:1) showed no remaining starting material (R_f 0.3) and the formation of a single product (R_f 0.9). Ethyl acetate (100 mL) was added and the mixture washed with hydrochloric acid (100 mL of a 1 M aqueous solution), sodium bicarbonate (100 mL of a saturated aqueous solution) and brine (100 mL), dried over $MgSO_4$, filtered and concentrated in vacuo. Recrystallisation from ethyl acetate/petrol yielded pivolate ester **18** (623 mg, 76%) as white needles. Purification of the recrystallisation residues by flash column chromatography (petrol–ethyl acetate, 7:2) gave further product (146 mg, 76% → 94%); mp 178–181 °C (ethyl acetate/petrol); $[\alpha]_D^{25} = +217.1$ (c 1.0, $CHCl_3$); ν_{max} (KBr) 1719 (s, C=O), 3508 (br, OH) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.26 (9H, s, C(CH_3)$_3$), 2.34 (3H, s, ArCH_3), 3.87 (1H, at, $J_{5,6} = J_{6,6'}$ 10.5 Hz, H-6), 4.20 (1H, at, $J_{3,4} = J_{4,5}$ 10.0 Hz, H-4), 4.26 (1H, dd, $J_{5,6'}$ 5.0 Hz, H-6′), 4.42–4.48 (2H, m, H-2, H-5), 5.38 (1H, dd, $J_{2,3}$ 3.5 Hz, H-3), 5.49 (1H, d, $J_{1,2}$ 1.0 Hz, H-1), 5.60 (1H, s, PhCH), 7.13–7.15 (2H, m, 2 × Ar-H), 7.35–7.39 (5H, m, 5 × Ar-H), 7.45–7.47 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.1 (q, ArCH$_3$), 27.1 (q, C(CH$_3$)$_3$), 39.1 (s, C(CH$_3$)$_3$), 64.9 (d, C-5), 68.5 (t, C-6), 70.5, 71.2 (d, C-2, C-3), 76.3 (d, C-4), 88.7 (d, C-1), 101.4 (d, PhCH), 125.9, 128.2, 129.9, 132.5 (4 × d, Ar-CH), 137.2, 138.1 (2 × s, Ar-C), 177.2 (s, C=O); m/z (ES^+) 482 (28), 481 (M + Na^+, 100), 459 (M + H^+, 18). (HRMS (ES^+) Calcd for $C_{25}H_{30}NaO_6S$ (MNa^+) 481.1661. Found 481.1668). (Found: C, 65.34; H, 6.64. $C_{25}H_{30}O_6S$ requires: C, 65.48; H, 6.59).

4.10. *para*-Tolyl 2-*O*-allyl-(*R*)-4,6-*O*-benzylidene-3-*O*-pivaloyl-1-thio-α-D-mannopyranoside 19

Ester **18** (140 mg, 0.30 mmol) and allyl bromide (0.079 mL, 0.91 mmol) were dissolved in DMF (0.4 mL) and the solution cooled to 0 °C. Sodium hydride (60% dispersion in mineral oil, 15 mg, 0.38 mmol) was added under argon. After 10 min, TLC (petrol–ethyl acetate, 5:1) showed no remaining starting material (R_f 0.15) and the formation of a major product (R_f 0.55) as well as some minor products. Ether (5 mL) was added, followed by ammonium chloride (5 mL of a saturated aqueous solution). The mixture was then diluted with further ether (45 mL) and washed with brine (3 × 20 mL), dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ether, 6:1) gave allyl ether **19** as a clear oil (112 mg, 74%); R_f 0.20 (petrol–ether, 6:1);

$[\alpha]_D^{24.5} = +119.5$ (*c* 1.0, $CHCl_3$); ν_{max} (thin film) 1647 (w, C=C), 1733 (s, C=O) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.26 (9H, s, $C(CH_3)_3$), 2.35 (3H, s, $ArCH_3$), 3.89 (1H, at, $J_{5,6} = J_{6,6'}$ 10.5 Hz, H-6), 4.07–4.12 (2H, m, $CH_2CH{=}CH_2$), 4.16 (1H, dd, $J_{1,2}$ 1.5 Hz, $J_{2,3}$ 3.5 Hz, H-2), 4.24 (1H, at, $J_{3,4} = J_{4,5}$ 10.0 Hz, H-4), 4.25 (1H, dd, $J_{5,6'}$ 4.5 Hz, H-6′), 4.42 (2H, ddd, H-5), 5.21 (1H, dd, J_Z 10.5 Hz, J_{gem} 1.5 Hz, $CH{=}CH_EH_Z$), 5.29 (1H, dd, J_E 15.5 Hz, $CH{=}CH_EH_Z$), 5.31 (1H, dd, H-3), 5.49 (1H, d, H-1), 5.62 (1H, s, PhC*H*), 5.84–5.94 (1H, m, $CH{=}CH_2$), 7.14–7.16 (2H, m, 2 × Ar-H), 7.35–7.39 (5H, m, 5 × Ar-H), 7.46–7.48 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.1 (q, $ArCH_3$), 27.1 (q, $C(CH_3)_3$), 39.0 (s, $C(CH_3)_3$), 65.4 (d, C-5), 68.5 (t, C-6), 70.4 (d, C-3), 72.4 (t, $CH_2CH{=}CH_2$), 76.4 (d, C-4), 77.8 (d, C-2), 87.1 (d, C-1), 101.2 (d, PhCH), 118.2 (t, $CH{=}CH_2$), 125.9, 128.1, 129.8, 129.9, 129.9, 132.3 (6 × d, Ar-CH), 133.9 (d, $CH{=}CH_2$), 137.3, 139.0 (2 × s, Ar-C), 177.8 (s, C=O); *m*/*z* (ES^+) 522 (33), 521 ($M + Na^+$, 100), 516 ($M + NH_4^+$, 36), 500 (22), 499 ($M + H^+$, 70), 393 (37). (HRMS (ES^+) Calcd for $C_{28}H_{34}O_6SNa$ (MNa^+) 521.1974. Found 521.1970). (Found: C, 67.30; H, 6.83. $C_{28}H_{34}O_6S$ requires: C, 67.45; H, 6.87).

4.11. *para*-Tolyl 4,6-*O*-benzylidene-3-*O*-pivaloyl-2-*O*-(prop-1-enyl)-1-thio-α-D-mannopyranoside 11

n-Butyllithium (1.6 M in hexanes, 100 μL) was added to a degassed solution of Wilkinson's catalyst (80 mg, 0.08 mmol) in tetrahydrofuran (3 mL). This mixture was stirred for 10 min before being added to a refluxing solution of allyl ether **19** (440 mg, 0.88 mmol) in tetrahydrofuran (4 mL). After 10 min, TLC (petrol–ether, 6:1) showed no remaining starting material (R_f 0.35) and the formation of a single product (R_f 0.50). The solution was allowed to cool to room temperature before the addition of dichloromethane (50 mL) and concentration in vacuo. Purification by flash column chromatography (petrol–ether, 9:1, with 1% added triethylamine) gave enol ethers **11**, as a white foam, an inseparable mixture of *E*- and *Z*-isomers (416 mg, 95%; *E*:*Z*, 1:2.5); ν_{max} (thin film) 1731 (m, C=O) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.23 (9H, s, $C(CH_3)_3$), 1.52 (<3H, dd, *J* 1.5 Hz, *J* 7.0 Hz, CH_{3E}), 1.64 (<3H, dd, *J* 1.5 Hz, *J* 7.0 Hz, CH_{3Z}), 2.35 (3H, s, $ArCH_3$), 3.90 (1H, at, $J_{5,6} = J_{6,6'}$ 10.5 Hz, H-6), 4.23–4.29 (2H, m, H-4, H-5), 4.39 (<1H, dd, $J_{1,2}$ 1.5 Hz, $J_{2,3}$ 3.5 Hz, H-2_Z), 4.42–4.52 (>2H, m, H-2_E, H-6′, CH_ECH_3, CH_ZCH_3), 5.30 (1H, dd, $J_{3,4}$ 10.5 Hz, H-3), 5.45 (<1H, d, H-1_Z), 5.49 (<1H, d, $J_{1,2}$ 1.0 Hz, H-1_E), 5.53 (<1H, s, $PhCH_E$), 5.62 (<1H, s, $PhCH_Z$), 5.88 (<1H, dd, *J* 6.0 Hz, $OCH_Z{=}CH$), 6.01–6.05 (<1H, m, $OCH_E{=}CH$), 7.13–7.15 (2H, m, 2 × Ar-H), 7.35–7.39 (5H, m, 5 × Ar-H), 7.46–7.49 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 9.4, 12.3 (2 × q, $CHCH_{3E}$, $CHCH_{3Z}$), 21.1 (q, $ArCH_3$), 27.0 (q, $C(CH_3)_3$), 39.0 (s, $C(CH_3)_3$), 65.0, 65.0, 69.9, 70.1, 76.2, 76.4, 77.2, 78.0, 79.6 (9 × d, C-2_E, C-3_E, C-4_E, C-5_E, C-2_Z, C-3_Z, C-4_Z, C-5_Z), 68.4, 68.5 (2 × t, C-6_E, C-6_Z), 86.6, 87.3 (2 × d, C-1_E, C-1_Z), 101.3 (d, CH_ECH_3, CH_ZCH_3), 102.6, 103.7 (2 × d, $PhCH_E$, $PhCH_Z$), 125.9, 128.2, 128.9, 129.9, 132.3, 132.5 (6 × d, Ar-CH), 129.4, 137.2, 138.2 (3 × s, Ar-C), 144.5, 145.3 (2 × d, $OCH_E{=}CH$, $OCH_Z{=}CH$), 177.8 (s, C=O); *m*/*z* (ES^+) 523 (27), 522 ($M + Na^+$, 76), 517 (20), 476 (28), 475 (30), 474 (100), 459 (28), 434 (37), 353 (100). (Found: C, 67.64; H, 6.89. $C_{28}H_{34}O_6S$ requires: C, 67.45; H, 6.87).

4.12. *para*-Tolyl 2-*O*-(2-iodo-1-(*para*-methoxyphenyl 3,6-di-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosid-4-*O*-yl)-propyl)-3,4,6-tri-*O*-benzyl-1-thio-α-D-mannopyranoside 23

General procedure A: Enol ethers **10** and alcohol **7** gave mixed acetals **23**, a partially separable mixture of diastereomers, as a clear foam (292 mg, 77%); ν_{max} (thin film) 1715 and 1777 (s and w, 2 × imide C=O) cm^{-1}; NMR data for major diastereomer: δ_H (500 MHz, $CDCl_3$) 1.60 (3H, d, *J* 7.3 Hz, $CHCH_3$), 2.37 (3H, s, $ArCH_3$), 3.64–3.97 (11H, m, H-4_{Glc}, H-5_{Glc}, H-6_{Glc}, H-$6'_{Glc}$, H-3_{Man}, H-4_{Man}, H-6_{Man}, H-$6'_{Man}$, OCH_3), 4.11 (1H, d, *J* 2.1 Hz, O_2CHCHI), 4.34–4.48 (8H, m, H-2_{Glc}, H-3_{Glc}, H-2_{Man}, H-5_{Man}, $PhCH_2$, PhCHH′, CHI), 4.52, 4.67 (2H, ABq, J_{AB} 11.9 Hz, $PhCH_2$), 4.53 (1H, d, *J* 12.2 Hz, PhCHH′), 4.59, 4.79 (2H, ABq, J_{AB} 10.9 Hz, $PhCH_2$), 4.72, 5.08 (2H, ABq, J_{AB} 13.1 Hz, $PhCH_2$), 5.59 (1H, d, $J_{1,2}$ 8.3 Hz, H-1_{Glc}), 6.29 (1H, s, H-1_{Man}), 6.64–6.72 (5H, m, 5 × Ar-H), 6.81–7.05 (6H, m, 6 × Ar-H), 7.20–7.90 (26H, m, 26 × Ar-H); partial NMR data for minor diastereomers: δ_H (500 MHz, $CDCl_3$) 1.76, 1.86 (2 × d, *J* 7.0 and 7.1 Hz, $CHCH_3$), 2.30, 2.34 (2 × s, $ArCH_3$), 5.38, 6.20 (2 × s, H-1_{Man}), 5.64 (d, $J_{1,2}$ 8.3 Hz, H-1_{Glc}); δ_C (125.7 MHz, $CDCl_3$) 21.2 (q, $ArCH_3$), 23.6 (q, $CHCH_3$), 29.6 (d, CHI), 55.5, 55.8 (d, q, C-2_{Glc}, OCH_3), 65.7, 67.6, 69.2, 72.5, 73.0, 73.8, 75.0, 75.5 (8 × t, C-6_{Glc}, C-6_{Man}, 5 × $PhCH_2$), 73.8, 75.3, 75.5, 75.9, 77.2, 79.8, 80.6 (7 × d, C-3_{Glc}, C-4_{Glc}, C-5_{Glc}, C-2_{Man}, C-3_{Man}, C-4_{Man}, C-5_{Man}), 86.5 (d, C-1_{Man}), 97.6 (d, C-1_{Glc}), 104.3 (d, O_2CHCHI), 114.2, 118.1, 118.6, 123.1, 126.6, 126.8, 127.1, 127.2, 127.3, 127.3, 127.5, 127.6, 127.7, 127.8, 127.8, 128.0, 128.1, 128.1, 128.2, 128.2, 128.3, 128.3, 128.5, 128.6, 128.7, 129.3, 130.1, 132.7, 133.2, 133.5 (30 × d, Ar-CH), 129.7, 137.6, 137.6, 137.9, 138.3, 138.7, 138.8 (7 × s, Ar-C), 150.7, 155.2 (2 × s, 2 × C=O); *m*/*z* (ES^+) 1343 (18), 1342 (35), 1341 (77), 1340 ($M + Na^+$, 100), 1337 (27), 1336 (62), 1335 ($M + NH_4^+$, 80). (Found: C, 66.02; H, 5.34; N, 1.30. $C_{72}H_{72}INO_{13}S$ requires: C, 65.60; H, 5.50; N, 1.06).

4.13. *para*-Tolyl 4,6-*O*-benzylidene-2-*O*-(2-iodo-1-(*para*-methoxyphenyl 3′,6′-di-*O*-benzyl-2′-deoxy-2′-phthalimido-β-D-glucopyranosyl-(1→4)-3,6-di-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosid-4′-*O*-yl)-propyl)-3-*O*-pivaloyl-1-thio-α-D-mannopyranoside 24

General procedure A: Enol ethers **11** and alcohol **20** gave mixed acetals **24**, an inseparable mixture of diastereomers, as a white foam, (102 mg, 75); ν_{max} (thin film) 1717 and 1775 (s and w, 2 × imide C=O, pivaloyl C=O) cm^{-1}; NMR data (diagnostic peaks): δ_H (400 MHz, $CDCl_3$) 1.26, 1.27 (9H, 2 × s, $C(CH_3)_3$), 1.67, 1.77 (3H, 2 × d, *J* 7.5 Hz, *J* 7.0 Hz, $CHCH_3$), 5.30 (1H, s, $PhCHO_2$), 5.43, 5.47 (2 × d, $J_{1,2}$ 8.0 Hz,

H-1_{Glc}), 5.69, 6.19 (1H, 2 × d, $J_{1,2}$ 1.0 Hz, 1.5 Hz, H-1_{Man}); *m/z* (ES^+) 1715 (64), 1714 ($M + Na^+$, 86), 1285 (100). (Found: C, 64.61; H, 5.30; N, 1.60. $C_{91}H_{91}INO_{20}S$ requires: C, 64.61; H, 5.42; N, 1.66).

4.14. Methyl 3,4,6-tri-*O*-benzyl-2-*O*-(2-iodo-1-(3,4,6-tri-*O*-benzyl-1-deoxy-1-fluoro-β-D-glucopyranos-2-*O*-yl)propyl)-α-D-glucopyranosyl-(1→3)-2,4,6-tri-*O*-benzyl-α-D-glucopyranosyl-(1→3)-2-*O*-benzyl-4,6-*O*-benzylidene-α-D-mannopyranoside 25

General procedure A: Enol ethers **12** and alcohol **21** gave mixed acetals **25**, an inseparable mixture of diastereomers, as a colourless oil (83 mg, 78) *m/z* (ES^+) 1878 ($M + Na^+$, 100).

4.15. 3,4,6-Tri-*O*-benzyl-2-*O*-(2-iodo-1-(methyl 2,3,6-tri-*O*-benzyl-α-D-mannopyranosid-4-*O*-yl)propyl)-α-D-mannopyranosyl fluoride 26

General procedure A: Enol ethers **6** and alcohol **22** gave mixed acetals **26**, an inseparable mixture of diastereomers, (139 mg, 55) as a colourless oil; *m/z* ($APCI^-$) 1117 ($M + Cl^-$, 8).

4.16. Phenyl 2-*O*-allyl-3,4,6-tri-*O*-benzyl-1-thio-β-D-glucopyranoside 30

Alcohol **29**[28] (700 mg, 1.29 mmol) was dissolved in DMF (6 mL) and the solution cooled to 0 °C. Sodium hydride (60% in mineral oil, 105 mg, 2.63 mmol) was added portionwise, followed by allyl bromide (0.22 mL, 2.54 mmol) and the reaction mixture allowed to return to room temperature. The solution was stirred for 2 h, after which time TLC (petrol–ethyl acetate, 5:1) showed no remaining starting material (R_f 0.25) and the formation of a major product (R_f 0.55). Methanol (5 mL) was slowly added and the mixture concentrated in vacuo. The residue was taken up in ether (50 mL), washed with brine (4 × 30 mL), dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 8:1) gave allyl ether **30** (566 mg, 75%) as a white solid; mp 58–59 °C (ether/petrol); $[\alpha]_D^{24.5} = -21.1$ (*c* 1.04, $CHCl_3$); ν_{max} (KBr) 1587 (w, C=C) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 3.41 (1H, dd, $J_{1,2}$ 9.5 Hz, $J_{2,3}$ 8.5 Hz, H-2), 3.52 (1H, ddd, $J_{4,5}$ 9.0 Hz, $J_{5,6}$ 1.5 Hz, $J_{5,6'}$ 4.5 Hz, H-5), 3.61–3.71 (2H, m, H-3, H-4), 3.73 (1H, dd, $J_{6,6'}$ 11.0 Hz, H-6), 3.80 (1H, dd, H-6′), 4.27 (1H, dd, J_{gem} 12.0 Hz, *J* 6.0 Hz, C*H*H′CH=CH_2), 4.40 (1H, dd, *J* 5.5 Hz, CHH′CH=CH_2), 4.54–4.64 (4H, m, H-1 and 3 × PhC*H*H′), 4.85 (1H, d, *J* 11.0 Hz, PhCH*H*′), 4.86 (1H, d, *J* 11.0 Hz, PhCH*H*′), 4.93 (1H, d, *J* 11.0 Hz, PhCH*H*′), 5.21 (1H, d, J_Z 10.5 Hz, CH=H_EH_Z), 5.31 (1H, dd, J_E 15.5 Hz, J_{gem} 1.5 Hz, CH=CH_EH_Z), 5.95–6.05 (1H, m, C*H*=CH_2), 7.21–7.36 (18H, m, 18 × Ar-H), 7.56–7.62 (2H, m, 2 × Ar-H); δ_C (100.6 MHz) 69.0, 73.4, 74.2, 75.0, 75.8 (5 × t, C-6, 3 × Ph*C*H_2, O*C*H_2CH=CH_2), 77.6, 79.0, 80.5, 86.7, 87.4 (5 × d, C-1, C-2, C-3, C-4, C-5), 117.4 (CH=*C*H_2), 127.3, 127.5, 127.6, 127.7, 127.8, 127.9, 128.3, 128.4, 128.4, 128.8, 131.8 (11 × d, Ar-CH), 133.8, 138.0, 138.2, 138.3 (4 × s, Ar-C), 134.6 (d, *C*H=CH_2); *m/z* ($APCI^+$) 605 ($M + Na^+$, 27), 181 (52), 173 (21), 155 (15), 145 (24), 143 (29), 131 (100), 129 (75), 121 (57), 111 (36). (Found: C, 74.46; H, 6.54. $C_{36}H_{38}O_5S$ requires: C, 74.20; H, 6.57).

4.17. Phenyl 3,4,6-tri-*O*-benzyl-2-*O*-(prop-1-enyl)-1-thio-β-D-glucopyranoside 31

n-Butyllithium (1.6 M in hexanes, 0.05 mL) was added to a degassed solution of Wilkinson's catalyst (43 mg, 0.046 mmol) in tetrahydrofuran (3 mL). This mixture was stirred for 10 min before being added to a refluxing solution of allyl ether **30** (269 mg, 0.46 mmol) in tetrahydrofuran (2 mL). After 1 h, TLC (petrol–ethyl acetate, 5:1) showed no remaining starting material (R_f 0.45) and the formation of a single product (R_f 0.55). The solution was allowed to cool to room temperature before the addition of dichloromethane (50 mL) and concentration in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 10:1, with 1% added triethylamine) gave enol ethers **31**, a semi-crystalline solid, as an inseparable mixture of *E*- and *Z*-isomers (257 mg, 96%, ca. 1:2, *E*:*Z*). ν_{max} (thin film) 1671 (m, C=C) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.57 (ca. 1H, dd, *J* 1.5 Hz, *J* 7.0 Hz, CH_{3E}), 1.66 (ca. 2H, dd, *J* 1.5 Hz, *J* 7.0 Hz, CH_{3Z}), 3.51–3.82 (6H, m, H-2, H-3, H-4, H-5, H-6, H-6′), 4.46 (<1H, dq, *J* 6.0 Hz, CH_3CH_Z), 4.54–4.68 (4H, m, H-1, $PhCH_2$, PhC*H*H′), 4.73, 4.83 (2H, ABq, J_{AB} 10.0 Hz, Ph*C*H_2), 4.84 (1H, d, *J* 11.0 Hz, PhCH*H*′), 5.02 (<1H, dq, *J* 12.0 Hz, CH_3CH_E), 6.03 (<1H, dd, *J* 1.5 Hz, OCH_Z=CH), 6.09 (<1H, dd, *J* 1.5 Hz, OCH_E=CH), 7.12–7.36 (18H, m, 18 × Ar-H), 7.57–7.60 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 9.4 (*C*H_{3Z}), 12.2 (*C*H_{3E}), 68.9 (t, C-6), 73.4, 75.1, 75.7 (3 × t, 3 × Ph*C*H_2), 77.2, 79.2, 81.5, 82.4, 86.0, 86.2 (6 × d, C-1, C-2, C-3, C-4, C-5), 100.3, 100.9 (2 × d, CH_3CH_E, CH_3CH_Z), 127.5, 127.6, 127.8, 127.8, 127.9, 127.9, 128.3, 128.4, 128.8, 132.9, 132.9 (11 × d, Ar-CH), 132.6, 138.0, 138.3 (3 × s, Ar-C), 146.5, 147.4 (2 × d, O*C*H_E=CH, O*C*H_Z=CH); *m/z* (ES^+) 606 (31), 605 ($M + Na^+$, 100), 600 ($M + NH_4^+$, 40). (HRMS (ES^+) Calcd for $C_{36}H_{38}NO_5SNa$ (MNa^+) 605.2338. Found 600.2330). (Found: C, 74.26; H, 6.49. $C_{36}H_{38}O_5S$ requires: C, 74.20; H, 6.57).

4.18. Phenyl 3,4,6-tri-*O*-benzyl-2-*O*-(2-iodo-1-methoxypropyl)-1-thio-β-D-glucopyranoside 32

Methanol (0.07 mL, 1.73 mmol) was added to 1,2-dichloroethane (2 mL) with molecular sieves (powdered, 4 Å, ca. 250 mg) and stirred for 1 h. After this time, enol ethers **31** (103 mg, 0.18 mmol), dissolved in 1,2-dichloroethane (2 mL), were added. *N*-Iodosuccinimide (100 mg, 0.44 mmol) was added and the solution immediately cooled to −78 °C. The solution was then allowed to return to room temperature over 14 h, after which time, TLC (petrol–ethyl acetate, 7:1) showed no remaining starting material (R_f 0.45) and the formation of a single product (R_f 0.40). Dichloromethane (50 mL) was added and the solution was filtered through Celite®, washed with sodium thiosulfate (25 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated

in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 7:1, with 1% added triethylamine) gave mixed acetals **32** as a clear oil, an inseparable mixture of diastereomers (126 mg, 96%); ν_{max} (thin film) no significant peaks; δ_H (400 MHz, $CDCl_3$) 1.72, 1.80, 1.93, 1.97 (3H, 3 × d, *J* 7.0 Hz, CHCH_3), 3.37, 3.42, 3.49 and 3.60 (3H, 4 × s [relative intensities: 2:6:1.5:1], OCH_3), 3.52–3.88 (6H, m, H-2, H-3, H-4, H-5, H-6, H-6′), 4.08–4.40 (1H, m, C*H*I), 4.45 (<1H, d, *J* 3.5 Hz, partial-O_2C*H*), 4.52–5.21 (>7H, m, H-1, 3 × PhCH_2, partial-O_2C*H*), 7.20–7.45 (18H, m, 18 × Ar-H), 7.57–7.60 (2H, m, 2 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.5, 21.9, 23.2 (3 × q, CH*C*H$_3$), 27.2, 28.2 (2 × d, *C*HI), 57.5, 58.0, 58.1 (3 × q, O*C*H$_3$), 69.0 (t, C-6), 73.3, 73.5, 74.6, 74.8, 75.1, 76.1, 76.2 (7 × t, 3 × Ph*C*H$_2$), 77.2, 77.3, 78.7, 78.8, 79.0, 85.6 (6 × d, C-2, C-3, C-4, C-5), 87.5, 87.7 (2 × d, C-1), 106.3, 106.4 (2 × d, O_2C*H*), 127.1, 127.3, 127.6, 127.6, 127.7, 127.8, 128.3, 128.3, 128.4, 128.5, 128.6, 128.6, 128.7, 129.1, 131.4, 131.5, 131.7 (17 × d, Ar-CH), 138.2, 138.2, 138.5 (3 × s, Ar-C); *m*/*z* (ES^+) 764 (22), 763 ($M + Na^+$, 47), 758 ($M + NH_4^+$, 100). (HRMS (ES^+) Calcd for $C_{37}H_{45}INO_6S$ (MNH_4^+) 758.2012. Found 758.2003).

4.19. Crossover experiment 1. Benzyl 3,4,6-tri-*O*-benzyl-β-D-mannopyranoside 34 and methyl 3,4,6-tri-*O*-benzyl-α-D-glucopyranoside 35

N-Iodosuccinimide (170 mg, 0.76 mmol), silver trifluoromethanesulfonate (39 mg, 0.15 mmol) and 2,6-di-*tert*-butyl-4-methyl-pyridine (112 mg, 0.55 mmol) were added to benzyl *manno* mixed acetal **33** (62 mg, 0.08 mmol), methyl *gluco* mixed acetal **32** (57 mg, 0.08 mmol) and molecular sieves (powdered, 4 Å, ca. 500 mg) in 1,2-dichloroethane (10 mL). This mixture was stirred at 50 °C for 2 h, after which time, TLC (petrol–ethyl acetate, 5:1) showed no remaining starting materials (R_f 0.85 and 0.75) and the formation of several more polar products. The mixture was allowed to cool to room temperature before the addition of dichloromethane (100 mL) and filtration through Celite®. The mixture was washed with sodium thiosulfate (50 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated in vacuo. A mixture of trifluoroacetic acid (4 mL), methanol (2 mL), tetrahydrofuran (2 mL), dichloromethane (4 mL) and water (1 mL) was added. After stirring at room temperature for 2 h, dichloromethane (20 mL) and sodium bicarbonate (50 mL of a saturated aqueous solution) were added and the mixture stirred for 30 min before the addition of additional dichloromethane (40 mL) and separation. The organic phase was washed with sodium bicarbonate (100 mL of a saturated aqueous solution) and the combined aqueous layers re-extracted with dichloromethane (50 mL). The combined organic extracts were washed with sodium thiosulfate (50 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated in vacuo. Partial purification by flash column chromatography (petrol–ethyl acetate, 5:2 → 2:1) gave benzyl β-mannoside **34** as a clear, colourless oil (23 mg, 56%); $[\alpha]_D^{25} = -40.7$ (*c* 0.7, $CHCl_3$) [lit.[12b] −50 (*c* 1.3, $CHCl_3$)]; δ_H (500 MHz, $CDCl_3$) 2.48 (1H, br s, OH-2), 3.42–3.45 (1H, m, H-5), 3.55 (1H, dd, $J_{2,3}$ 2.9 Hz, $J_{3,4}$ 8.9 Hz, H-3), 3.75 (1H, dd, $J_{5,6}$ 5.3 Hz, $J_{6,6'}$ 10.7 Hz, H-6), 3.80 (1H, at, *J* 10.4 Hz, H-6′), 3.89 (1H, at, *J* 9.3 Hz, H-4), 4.12 (1H, d, H-2), 4.46 (1H, s, H-1), 4.55, 4.90 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 4.59, 4.66 (2H, ABq, J_{AB} 11.9 Hz, PhCH_2), 4.66, 4.76 (2H, ABq, J_{AB} 11.9 Hz, PhCH_2), 4.67, 4.96 (2H, ABq, J_{AB} 11.7 Hz, PhCH_2), 7.20–7.38 (20H, m, Ar-H); HSQC (400 MHz, $CDCl_3$) $^1J_{C\text{-}1,H\text{-}1}$ 157 Hz; and methyl α-glucoside **35** as white crystals (19 mg, 52%); mp 87–89 °C (ether/petrol) [lit.[10b] mp 89–90 °C]; $[\alpha]_D^{24.5} = +89.0$ (*c* 1.01, $CHCl_3$) [lit.[10b] $[\alpha]_D^{23} = +90$ (*c* 1.1, $CHCl_3$)]; δ_H (400 MHz, $CDCl_3$) 2.11 (1H, d, $J_{2,OH}$ 8.0 Hz, O*H*), 3.43 (3H, s, OCH_3), 3.61–3.79 (6H, m, H-2, H-3, H-4, H-5, H-6, H-6′), 4.51, 4.83 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 4.53, 4.66 (2H, ABq, J_{AB} 12.0 Hz, PhCH_2), 4.82 (1H, d, $J_{1,2}$ 3.0 Hz, H-1), 4.86, 4.92 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 7.15–7.48 (15H, m, 15 × Ar-H). No trace of crossover products was observed by ^{1}H NMR or TLC.

4.20. 2-*O*-(2-Iodo-1-benzyloxy-propyl)-3,4,6-tri-*O*-benzyl-α-D-glucopyranosyl fluoride 36

Benzyl alcohol (29 μL, 0.28 mmol) was dissolved in 1,2-dichloroethane (1 mL) with molecular sieves (powdered, 4 Å, ca. 100 mg) and stirred for 1 h. After this time, enol ethers **6** (70 mg, 0.14 mmol), dissolved in 1,2-dichloroethane (1 mL), were added. *N*-Iodosuccinimide (96 mg, 0.43 mmol) was added and the solution immediately cooled to −40 °C. The solution was warmed to room temperature over 3 h, after which time dichloromethane (20 mL) was added, the solution filtered through Celite®, washed with sodium thiosulfate (10 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 5:1, with 1% added triethylamine) gave mixed acetals **36** as a clear oil, an inseparable mixture of diastereomers (91 mg, 88%); *m*/*z* (ES^+) 749 ($M + Na^+$, 35), 748 (100), 747 (80), 743 ($M + NH_4^+$, 30). (HRMS (ES^+) Calcd for $C_{37}H_{44}FINO_6$ (MNH_4^+) 744.2197. Found 744.2195).

4.21. Crossover experiment 2. Benzyl 3,4,6-tri-*O*-benzyl-β-D-mannopyranoside 34 and methyl 3,4,6-tri-*O*-benzyl-α-D-glucopyranoside 35

Molecular sieves (4 Å) were suspended in anhydrous dichloroethane (1 mL) in a flame-dried flask under Ar. 2,6-Di-*tert*-butyl-4-methylpyridine (55 mg, 0.27 mmol), silver trifluoromethanesulfonate (69 mg, 0.27 mmol) and anhydrous tin(II) chloride (51 mg, 0.27 mmol) were added. Methyl *gluco* mixed acetal **37** (45 mg, 0.069 mmol) and benzyl *manno* mixed acetal **36** (47 mg, 0.065 mmol) were dissolved in anhydrous dichloroethane (7 mL) and added via cannula under Ar. The reaction mixture was then stirred at 50 °C. After 5 h, TLC (petrol–ethyl acetate, 2:1) indicated the absence of any starting materials (R_f 0.7 and 0.6) and the formation of two major products (R_f 0.2 and 0.3). The reaction was quenched with $NaHCO_3$ (10 mL of a saturated aqueous solution) and stirred for a further 10 min. The mixture was filtered through Celite®, diluted with CH_2Cl_2 (100 mL) and washed with brine (50 mL).

The organic layer was dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was purified by flash column chromatography (petrol–ethyl acetate, 5:2 → 2:1) to afford benzyl β-mannoside **34** (21 mg, 60%) as a colourless oil and methyl α-glucoside **35** (19 mg, 59%) as white crystals, both identical to those described above. No trace of crossover products was observed by ^{1}H NMR or TLC.

4.22. 3,4,6-Tri-*O*-benzyl-2-*O*-(2-iodo-1-(methyl 2,3-di-*O*-benzyl-α-D-glucopyranosid-6-*O*-yl)propyl)-α-D-mannopyranosyl fluoride 39

N-Iodosuccinimide (206 mg, 0.92 mmol) and 4 Å molecular sieves were added to anhydrous dichloroethane (2 mL) and cooled to −40 °C under Ar. Diol **38**[35] (228 mg, 0.61 mmol) was dissolved in anhydrous dichloroethane (2 mL) and added to the reaction vessel by cannula under Ar. Enol ethers **6** (150 mg, 0.30 mmol) were dissolved in anhydrous dichloroethane (2 mL) and added to the reaction vessel by cannula under Ar. The reaction was stirred in the dark and allowed to warm to room temperature. After 19 h, TLC (petrol–ethyl acetate, 2:1) indicated the formation of a product (R_f 0.5) and the complete consumption of the enol ether (R_f 0.8). The reaction was quenched with 10% aqueous sodium thiosulfate (30 mL) and then extracted with CH_2Cl_2 (2 × 30 mL). The combined organic extracts were dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was purified by flash column chromatography (petrol–ethyl acetate, 3:1) to afford mixed acetals **39** (220 mg, 73%) as a colourless oil; *m/z* (APCI$^+$) 1048 (M+56, 60), 1010 (M + NH_4^+, 22). (HRMS Calcd for $C_{51}H_{62}NO_{11}IF$ (MNH_4^+) 1010.3352. Found 1010.3362).

4.23. *para*-Tolyl 3,4,6-tri-*O*-benzyl-2-*O*-(2-iodo-1-(*para*-methoxyphenyl 3-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranosid-6-*O*-yl)-propyl)-1-thio-α-D-mannopyranoside 41

Diol **40** (101 mg, 0.20 mmol) and enol ethers **10** (116 mg, 0.19 mmol) were dissolved in 1,2-dichloroethane (5 mL) with molecular sieves (powdered, 4 Å, ca. 250 mg). *N*-Iodosuccinimide (110 mg, 0.49 mmol) was added and the resulting mixture cooled immediately to −78 °C. The solution was allowed to return to room temperature over 17 h, after which time, TLC (petrol–ethyl acetate, 3:1) showed no remaining starting material (R_f 0.8) and the formation of several products. Dichloromethane (50 mL) was added and the solution filtered through Celite®, washed with sodium thiosulfate (50 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 4:1 → 3:1) gave mixed acetals **41** as a clear oil, an inseparable mixture of diastereomers (143 mg, 60%; three major diastereomers, ratio 1:1.5:5); R_f 0.35 (petrol–ethyl acetate, 2:1); ν_{max} (thin film) 1714 and 1776 (s and w, 2 × imide C=O) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 1.83, 1.87, 1.90 (3H, 3 × d, *J* 7.0 Hz, CHCH_3), 2.24, 2.28, 2.33 (3H, 3 × s, ArCH_3), 3.22, 3.32, 3.37 (1H, 3 × d, $J_{4,OH}$ 4.5 Hz, 4.0 Hz, 3.0 Hz, O*H*), 3.53–3.58 (1H, m, H-5$_{Man}$), 3.62, 3.69, 3.71 (3H, 3 × s, OCH_3), 3.68–3.75 (1H, m, H-6$_{Man}$), 3.78–3.94, 4.00–4.34 (10H, 2 × m, H-2$_{Man}$, H-3$_{Man}$, H-4$_{Man}$, H-6′$_{Man}$, H-3$_{Glc}$, H-4$_{Glc}$, H-5$_{Glc}$, H-6$_{Glc}$, H-6′$_{Glc}$, C*H*I), 4.40–4.96 (10H, m, H-2$_{Glc}$, C*H*CHICH$_3$, 4 × PhCH_2), 5.55, 5.74, 5.80 (1H, 3 × d, $J_{1,2}$ 1.5, 1.0, 1.0 Hz, H-1$_{Man}$), 5.57, 5.62, 5.69 (1H, 3 × d, $J_{1,2}$ 8.5 Hz, H-1$_{Glc}$), 6.67–6.99 (4H, m, 4 × Ar-H), 7.06–7.10 (6H, m, 6 × Ar-H), 7.20–7.42 (18H, m, 18 × Ar-H), 7.70–8.00 (4H, br, 4 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 21.0, 21.1, 21.1 (3 × q, Ar*C*H$_3$), 22.2, 23.8, 23.9 (3 × q, CH*C*H$_3$), 25.0, 26.0 (2 × d, *C*HI), 55.3, 55.5, 55.5 (3 × d/q, C-2$_{Glc}$, OCH_3), 61.9 (t, C-6$_{Glc}$), 68.8 (t, C-6$_{Man}$), 71.5, 73.3, 74.0, 74.3, 75.2, 75.3 (5 × t, 4 × PhCH_2), 72.3, 72.3, 72.6, 72.8, 74.5, 74.7, 76.7, 77.0, 77.2, 77.3, 78.1, 78.6, 80.0, 80.3 (14 × d, C-2$_{Man}$, C-3$_{Man}$, C-4$_{Man}$, C-5$_{Man}$, C-3$_{Glc}$, C-4$_{Glc}$, C-5$_{Glc}$), 87.2, 87.8 (2 × d, C-1$_{Man}$), 97.8, 98.0 (2 × d, C-1$_{Glc}$), 105.5, 105.9 (2 × d, *C*HCHICH$_3$), 114.3, 114.3, 114.3, 118.9, 119.1, 119.2, 123.4, 127.3, 127.3, 127.5, 127.7, 127.8, 127.8, 127.9, 127.9, 127.9, 128.0, 128.0, 128.1, 128.1, 128.1, 128.2, 128.2, 128.3, 128.4, 128.4, 128.5, 129.9, 130.0, 130.1, 130.1, 131.4, 131.8, 132.8, 133.8 (35 × d, Ar-CH), 137.7, 137.8, 137.9, 138.2, 138.3, 138.4 (6 × s, Ar-C), 150.8, 155.3, 155.4 (3 × s, *C*=O); *m/z* (ES$^+$) 1251 (50), 1250 (M + Na$^+$, 62), 1247 (35), 1246 (68), 1245 (M + NH_4^+, 100). (Isotope distribution M + NH_4^+: first isotopic peak *m/z* 1245.42 (100), second isotopic peak *m/z* 1246.44 (81), third isotopic peak *m/z* 1247.44 (35), fourth isotopic peak *m/z* 1248.44 (13). Calcd for $C_{65}H_{70}IN_2O_{13}S$: first isotopic peak *m/z* 1245.36 (100), second isotopic peak *m/z* 1246.37 (68), third isotopic peak *m/z* 1247.37 (35), fourth isotopic peak *m/z* 1248.37 (12)). Other products (63 mg, 39%) were identified as succinimide-containing mixed acetals.

4.24. Methyl 3,4,6-tri-*O*-benzyl-β-D-mannopyranosyl-(1→6)-2,3-di-*O*-benzyl-α-D-glucopyranoside 42 and methyl 3,4,6-tri-*O*-benzyl-α-D-mannopyranosyl-(1→4)-2,3-di-*O*-benzyl-α-D-glucopyranoside 43

Molecular sieves (4 Å) were suspended in anhydrous dichloroethane (1 mL) in a flame-dried flask under Ar. 2,6-Di-*tert*-butyl-4-methylpyridine (67 mg, 0.33 mmol), silver trifluoromethanesulfonate (84 mg, 0.33 mmol) and anhydrous tin(II) chloride (62 mg, 0.33 mmol) were added. Mixed acetals **39** (162 mg, 0.16 mmol) were dissolved in anhydrous dichloroethane (4 mL) and added by cannula under Ar and the reaction mixture stirred at 50 °C. After 22 h, TLC (petrol–ethyl acetate, 3:1) showed the absence of any starting material (R_f 0.2) and the formation of two major products (R_f 0.3 and 0.1). The reaction mixture was diluted with ether (50 mL), filtered through Celite and washed with $NaHCO_3$ (30 mL of a saturated aqueous solution). The organic layer was dried over $MgSO_4$, filtered and concentrated in vacuo. The residue was then dissolved in THF/TFA/methanol/water (2:5:1:2, 2.5 mL) and stirred at room temperature. After 72 h, TLC (petrol–ethyl acetate, 1:2) indicated the formation of two products (R_f 0.6, 0.7) and little remaining starting material (R_f 0.8). The reaction mixture was concentrated in vacuo. The residue was purified by flash column chromatography

(petrol–ethyl acetate, 1:1) to afford α(1→4) disaccharide **43** (13 mg, 12%) as a colourless oil; $[\alpha]_D^{24} = +33.1$ (*c* 0.45, $CHCl_3$); ν_{max} 3451 (br, OH) cm^{-1}; δ_H (500 MHz, $CDCl_3$) 2.09 (1H, br s, OH-2), 3.37 (1H, br s, OH-6), 3.38 (3H, s, OCH_3), 3.48 (1H, dd, $J_{5,6}$ 8.1 Hz, $J_{6,6'}$ 9.9 Hz, H-6_b), 3.52–3.57 (2H, m, H-2_a, H-5_a), 3.57 (1H, dd, $J_{3,4}$ 8.7 Hz, $J_{4,5}$ 9.5 Hz, H-4_b), 3.65–3.70 (2H, m, H-6_a, H-$6'_b$), 3.75 (1H, dd, $J_{2,3}$ 3.2 Hz, H-3_b), 3.77–3.78 (1H, m, H-2_b), 3.80–3.85 (1H, m, H-5_b), 3.87–3.92 (3H, m, H-3_a, H-4_a, H-$6'_a$), 4.45, 4.78 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 4.54 (2H, s, PhCH_2), 4.58 (1H, d, $J_{1,2}$ 3.7 Hz, H-1_a), 4.59, 4.63 (2H, ABq, J_{AB} 11.7 Hz, PhCH_2), 4.63, 4.75 (2H, ABq, J_{AB} 12.2 Hz, PhCH_2), 4.63, 5.01 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 5.37 (1H, d, $J_{1,2}$ 1.5 Hz, H-1_b), 7.14–7.38 (25H, m, Ar-H); δ_C (125.7 MHz, $CDCl_3$) 55.1 (q, OCH_3), 60.2 (t, C-6_a), 68.6 (d, C-2_b), 69.1 (t, C-6_b), 70.4 (d, C-5_a), 72.0, 73.2, 73.4, 74.9, 75.5 (5 × t, 5 × PhCH_2), 72.2 (d, C-5_b), 74.3 (d, C-4_b), 74.8 (d, C-4_a), 79.8, 79.9 (2 × d, C-2_a, C-3_b), 81.9 (d, C-3_a), 97.9 (d, $^1J_{C\text{-}1,H\text{-}1}$ 166.4 Hz, C-1_a), 101.1 (d, $^1J_{C\text{-}1,H\text{-}1}$ 172.5 Hz, C-1_b), 127.5, 127.7, 127.7, 127.8, 127.9, 128.0, 128.0, 128.1, 128.3, 128.3, 128.4 (11 × d, Ar-CH), 137.2, 137.7, 137.7, 137.8, 138.4 (5 × s, Ar-C); *m*/*z* (ES^+) 829 (M + Na^+, 70), 824 (M + NH_4^+, 100) (HRMS Calcd for $C_{48}H_{58}NO_{11}$ (MNH_4^+) 824.4010. Found 824.4016) and β(1→6) disaccharide **42**[6b] (36 mg, 29%) as a colourless oil; $[\alpha]_D^{24} = -3.2$ (*c* 0.25, $CHCl_3$); δ_H (500 MHz, $CDCl_3$) 2.43 (2H, br s, 2 × OH), 3.37 (3H, s, OCH_3), 3.41–3.52 (3H, m, H-2_a, H-4_a, H-5_b), 3.54 (1H, dd, $J_{2,3}$ 3.0 Hz, $J_{3,4}$ 8.9 Hz, H-3_b), 3.68–3.77 (4H, m, H-5_a, H-6_a, H-6_b, H-$6'_b$), 3.79 (1H, at, *J* 9.1 Hz, H-3_a), 3.87 (1H, at, *J* 9.3 Hz, H-4_b), 4.11 (1H, d, H-2_b), 4.13–4.16 (1H, m, H-$6'_a$), 4.48 (1H, s, H-1_b), 4.53, 4.89 (2H, ABq, J_{AB} 10.8 Hz, PhCH_2), 4.55, 4.61 (2H, ABq, J_{AB} 12.2 Hz, PhCH_2), 4.60 (1H, d, $J_{1,2}$ 3.6 Hz, H-1_a), 4.66, 4.77 (2H, ABq, J_{AB} 11.9 Hz, PhCH_2), 4.67, 4.78 (2H, ABq, J_{AB} 12.2 Hz, PhCH_2), 4.74, 5.02 (2H, ABq, J_{AB} 11.4 Hz, PhCH_2), 7.20–7.40 (25H, m, Ar-H); δ_C (100.6 MHz, $CDCl_3$) 55.2 (q, OCH_3), 68.1 (d, C-2_b), 68.7 (t, C-6_a), 69.1 (t, C-6_b), 70.0 (d, C-5_a), 70.6 (d, C-4_a), 71.3, 73.1, 73.4, 75.2, 75.1 (5 × t, 5 × PhCH_2), 74.1 (d, C-4_b), 75.1 (d, C-5_b), 79.5 (d, C-2_a), 81.3, 81.3 (2 × d, C-3_a, C-3_b), 98.0 (d, $^1J_{C\text{-}1,H\text{-}1}$ 168.9 Hz, C-1_a), 100.0 (d, $^1J_{C\text{-}1,H\text{-}1}$ 157.5 Hz, C-1_b), 127.5, 127.7, 127.8, 127.8, 127.9, 128.0, 128.0, 128.1, 128.3, 128.3, 128.4, 128.5, 128.6 (13 × d, Ar-CH), 137.8, 137.9, 138.1, 138.7 (4 × s, Ar-C).

4.25. *para*-Methoxyphenyl 3,4,6-tri-*O*-benzyl-α-D-mannopyranosyl-(1→4)-3-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranoside 45 and *para*-methoxyphenyl 3,4,6-tri-*O*-benzyl-β-D-mannopyranosyl-(1→6)-3-*O*-benzyl-2-deoxy-2-phthalimido-β-D-glucopyranoside 44

Mixed acetals **41** (127 mg, 0.10 mmol) were dissolved in 1,2-dichloroethane (10 mL) with molecular sieves (powdered, 4 Å, ca. 500 mg). 2,6-Di-*tert*-butyl-4-methylpyridine (54 mg, 0.26 mmol), *N*-iodosuccinimide (58 mg, 0.25 mmol) and silver trifluoromethanesulfonate (29 mg, 0.11 mmol) were added and the resulting mixture heated to 50 °C. After 2 days, TLC (petrol–ethyl acetate, 1:1) showed material coincident with the starting material (R_f 0.65) and the formation of two other major products (R_f 0.55, 0.45). The mixture was allowed to cool to room temperature and then dichloromethane (50 mL) added and the solution filtered through Celite®, washed with sodium thiosulfate (50 mL of a 10% aqueous solution), dried over $MgSO_4$, filtered and concentrated in vacuo. The crude mixture was treated with trifluoroacetic acid, tetrahydrofuran, methanol and water (5:2:2:1, 6 mL) for 5 days. After this time, sodium bicarbonate (20 mL of a saturated aqueous solution) was added and the mixture extracted with dichloromethane (50 mL). The organic layer was washed with sodium bicarbonate (50 mL of a saturated aqueous solution) and brine (50 mL), dried over $MgSO_4$, filtered and concentrated in vacuo. Purification by flash column chromatography (petrol–ethyl acetate, 2:3) gave β(1→6) disaccharide **44** as a clear oil (16 mg, 16%); R_f 0.1 (petrol–ethyl acetate, 1:1); $[\alpha]_D^{22} = +21.2$ (*c* 0.33, $CHCl_3$); ν_{max} (thin film) 1714 and 1774 (s and w, 2 × imide C=O), 3433 (br, OH) cm^{-1}; δ_H (500 MHz, $CDCl_3$) 3.18 (1H, d, $J_{4,OH}$ 6.5 Hz, O*H*), 3.48 (1H, ddd, $J_{4,5}$ 9.5 Hz, $J_{5,6}$ 5.0 Hz, $J_{5,6'}$ 2.0 Hz, H-5_{Man}), 3.54 (1H, dd, $J_{2,3}$ 3.0 Hz, $J_{3,4}$ 9.0 Hz, H-3_{Man}), 3.70 (3H, s, OCH_3), 3.72–3.88 (5H, m, H-6_{Man}H-$6'_{Man}$, H-4_{Glc}, H-5_{Glc}, H-6_{Glc}), 3.91 (1H, at, H-4_{Man}), 3.99 (1H, dd, $J_{5,6'}$ 6.0 Hz, $J_{6,6'}$ 11.0 Hz, H-$6'_{Glc}$), 4.15 (1H, d, H-2_{Man}), 4.26–4.38 (2H, m, H-2_{Glc}, H-3_{Glc}), 4.43–4.68 (6H, m, H-1_{Man}, PhCH_2, 3 × PhC*H*H′), 4.77 (1H, d, *J* 12.0 Hz, PhCH*H*′), 4.80 (1H, d, *J* 12.0 Hz, PhCH*H*′), 4.90 (1H, d, *J* 11.0 Hz, PhCH*H*′), 5.75 (1H, d, $J_{1,2}$ 8.5 Hz, H-1_{Glc}), 6.70–8.00 (28H, m, 28 × Ar-H); δ_C (125.7 MHz, $CDCl_3$) 55.2, 55.4 (d, q, C-2_{Glc}, OCH_3), 69.3, 71.4, 73.9, 74.6, 74.9 (5 × t, C-6_{Glc}, C-6_{Man}, 4 × PhCH_2), 67.9, 68.9, 73.4, 74.4, 74.9, 78.7, 81.3 (7 × d, C-2_{Man}, C-3_{Man}, C-4_{Man}, C-5_{Man}, C-3_{Glc}, C-4_{Glc}, C-5_{Glc}), 97.0 (d, $^1J_{C1\text{-}H1}$ 169 Hz, C-1_{Glc}), 99.9 (d, $^1J_{C1\text{-}H1}$ 160 Hz, C-1_{Man}), 114.3, 118.2, 123.3, 127.4, 127.6, 127.6, 127.8, 127.8, 128.0, 128.1, 128.2, 128.3, 128.4, 131.4, 133.8 (15 × d, Ar-CH), 137.6, 137.9, 137.9, 138.0 (4 × s, Ar-C), 150.5, 155.2 (2 × s, *C*=O); *m*/*z* (ES^+) 961 (32), 960 (M + Na^+, 51), 956 (57), 955 (M + NH_4^+, 100) (HRMS (ES^+) Calcd for $C_{55}H_{59}N_2O_{13}$ (MNH_4^+) 955.4017. Found 955.4019) and α(1→4) disaccharide **45** as a clear oil, (29 mg, 30%); R_f 0.55 (ethyl acetate–petrol, 3:2); $[\alpha]_D^{22} = +73.9$ (*c* 0.7, $CHCl_3$); ν_{max} (thin film) 1714 and 1774 (s and w, 2 × imide C=O), 3474 (br, OH) cm^{-1}; δ_H (400 MHz, $CDCl_3$) 3.12 (1H, at, *J* 6.5 Hz, O*H*), 3.52–3.55 (1H, m, H-4_{Glc}), 3.60 (1H, dd, $J_{5,6}$ 6.5 Hz, $J'_{6,6}$ 10.0 Hz, H-6_{Man}), 3.68–3.98 (8H, m, H-2_{Man}, H-3_{Man}, H-4_{Man}, H-5_{Man}, H-$6'_{Man}$, H-5_{Glc}, H-6_{Glc}, H-$6'_{Glc}$), 3.71 (3H, s, OCH_3), 4.09–4.13 (1H, m, H-3_{Glc}), 4.30, 4.69 (2H, ABq, J_{AB} 12.0 Hz, PhCH_2), 4.45–4.46 (1H, m, H-2_{Glc}), 4.48, 4.80 (2H, ABq, J_{AB} 11.0 Hz, PhCH_2), 4.56, 4.61 (2H, ABq, J_{AB} 12.0 Hz, PhCH_2), 4.63, 4.69 (2H, ABq, J_{AB} 11.5 Hz, PhCH_2), 5.37 (1H, d, $J_{1,2}$ 2.0 Hz, H-1_{Man}), 5.61 (1H, d, $J_{1,2}$ 8.5 Hz, H-1_{Glc}), 6.68–7.90 (28H, m, 28 × Ar-H); δ_C (100.6 MHz, $CDCl_3$) 55.6, 55.7 (d, q, C-2_{Glc}, OCH_3), 68.5, 72.3, 73.5, 75.4 (4 × t, C-6_{Glc}, C-6_{Man}, 4 × PhCH_2), 69.0, 72.5, 75.1, 79.8, 80.9 (5 × d, C-2_{Man}, C-3_{Man}, C-4_{Man}, C-5_{Man}, C-3_{Glc}, C-4_{Glc}, C-5_{Glc}), 97.5 (d, $^1J_{C1\text{-}H1}$ 167 Hz, C-1_{Glc}), 101.2 (d, $^1J_{C1\text{-}H1}$ 173 Hz, C-1_{Man}), 114.4, 118.8, 127.5, 127.6, 127.8, 127.9, 128.1, 128.2, 128.4, 128.6, 137.6 (11 × d, Ar-CH) 150.8 (s, *C*=O). (HRMS (ES^+) $C_{55}H_{59}N_2O_{13}$ (MNH_4^+) 955.4017. Found 955.4025).

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