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Synthesis of oligosaccharides as potential inhibitors of mycobacterial arabinosyltransferases. Di- and trisaccharides containing C-5 modified arabinofuranosyl residues

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Abstract—The synthesis of a panel of oligosaccharides containing C-5 arabinofuranosyl residues (**9**–**20**) is described. These compounds are of interest as potential inhibitors of the α-(1 → 5)-arabinosyltransferase involved in the assembly of mycobacterial cell-wall arabinan. In the series of compounds prepared, the 5-OH group on the nonreducing residue(s) is replaced, independently, with an amino, azido, fluoro, or methoxy functionality. The synthesis of the target compounds involved the preparation of a series of C-5 modified arabinofuranosyl thioglycosides (**24**–**26**) and their subsequent coupling to the appropriate acceptor species (**21**–**23**). Deprotection of the glycosylation products afforded the azido, fluoro, or methoxy analogs directly. The amino derivatives were obtained in one additional step by reduction of the azido compounds.

1. Introduction

Mycobacterial infections have recently attracted significant attention from international health agencies.[1] The increased interest in these diseases, most notably tuberculosis, is a consequence of a number of factors. Among these are the emergence of drug-resistant mycobacterial strains,[2,3] the particular susceptibility of immunocompromised (e.g., HIV-positive) individuals to mycobacterial infections,[4,5] the difficulty in treating these infections in HIV-positive patients,[6,7] and the lack of research over the last few decades in the area of antimycobacterial drug identification.[2,8] The arsenal of drugs available for the treatment of mycobacterial diseases is relatively small.[9] This reality, combined with the issues mentioned above, make clear the importance of increased research focused on the development of new therapeutics for the treatment of mycobacterial diseases. The designation[10] of drug-resistant *Mycobacterium tuberculosis* as a Class C bioterrorism agent has further underscored the urgency of this task.

A morphological feature common to all mycobacteria is a complicated cell wall that provides the organism with a great deal of protection from its environment.[11,12] The survival of the organism depends upon its ability to synthesize a complete cell-wall complex, and, therefore, compounds that inhibit the enzymes that are involved in its assembly should have potential as antimycobacterial drugs.[13,14] Two polysaccharides, an arabinogalactan (AG) and a lipoarabinomannan (LAM), comprise a significant portion of the cell wall. These glycans are unusual in that all of the arabinose and galactose residues are in the furanose ring form. Galactofuranose- and arabinofuranose-containing glycoconjugates are not found in mammals, and hence the enzymes that assemble these glycans are extremely attractive targets for drug action.[15,16] In recent years, we have reported synthetic and conformational studies that are aimed at the development of new antimycobacterial agents that act by inhibiting the glycosyltransferases involved in the biosynthesis of the arabinan portions of AG and LAM.[17–22] Previous studies have shown that the

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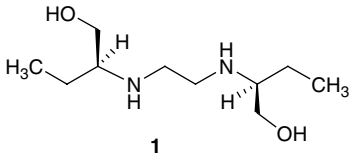
antituberculosis drug, (*S*,*S*)-ethambutol (**1**), inhibits one or more of the arabinosyltransferases (AraT's) involved in mycobacterial arabinan biosynthesis.[23–25] We have, therefore, focused our attention on identifying new inhibitors of mycobacterial AraT's. Ours is one of an increasing number of research groups that are working in this area[26–29].



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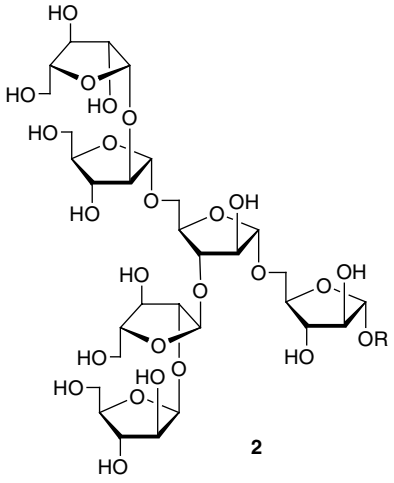

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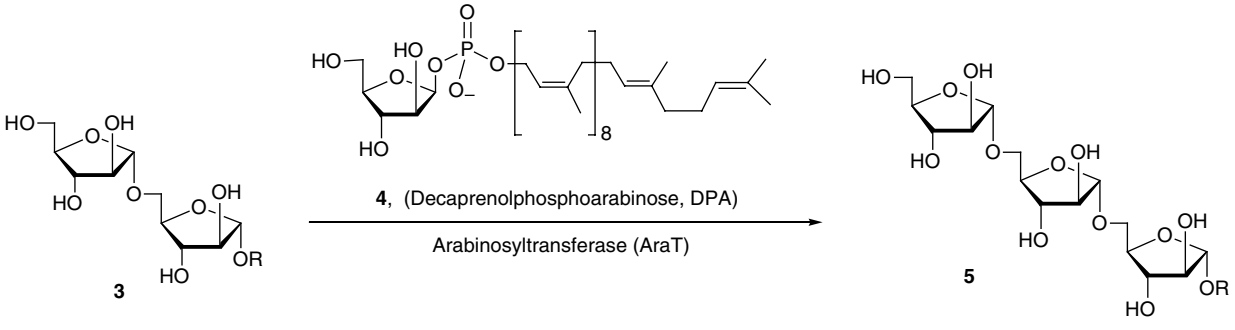
The arabinan portions of AG and LAM are nearly identical in structure. At the core is a linear α-(1 → 5)-linked chain of arabinofuranose residues containing periodic α-(1 → 3)-linked sugar moieties from which additional α-(1 → 5)-linked arabinan chains are attached. At the nonreducing termini of each linear chain is the hexasaccharide **2**. A family of AraT's that produce α-(1 → 5)-, α-(1 → 3)-, and β-(1 → 2)-arabinofuranosyl linkages is believed to be involved in the biosynthesis of the polysaccharide. A hypothetical example of an AraT-catalyzed reaction is shown in Figure 1. Polymer growth involves the coupling of an oligosaccharide acceptor (e.g., **3**), with decaprenolphosphoarabinose (DPA, **4**)[30,31] to afford an elongated oligosaccharide **5**. It has also been suggested[32] that another activated donor (e.g., a sugar nucleotide) may be used in the assembly of these polysaccharides. The presence of UDP-Ara*f* in mycobacteria has been reported,[33] but incorporation of this donor into arabinan has not been demonstrated. Analogs of DPA, a possible sugar nucleotide donor, or oligosaccharide substrates such as **5** are potential AraT inhibitors.

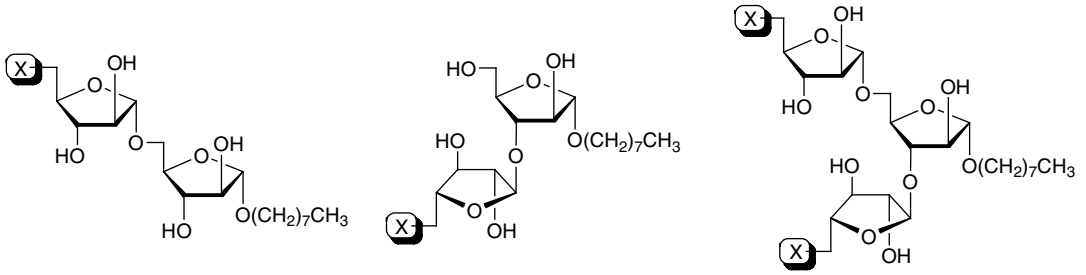
To date, the majority of investigations addressing the identification of glycosyltransferase inhibitors have targeted mammalian enzymes, and in those studies the focus has largely been on the preparation of acceptor analogs.[34] These analogs, in which specific hydroxyl groups have been replaced with other functionalities (e.g., fluoro, methoxy, amino), have been widely used in mapping out the substrate specificity of glycosyltransferases and other carbohydrate-recognizing proteins.[35–39] These studies have not only enabled the identification of 'key polar groups'[40] involved in the recognition of oligosaccharides by the proteins, but have also identified potent inhibitors of these enzymes. For example, the most potent specific glycosyltransferase inhibitor reported to date is an analog in which the reactive hydroxyl group on the acceptor is replaced with an amino group.[41,42] This compound inhibits the blood group A glycosyltransferase and possesses a 200 nM K_i well below the K_m for the natural disaccharide acceptor (2 μM).

Oligosaccharides **6**–**8** have been shown to be substrates for mycobacterial AraT's.[17,32] Analogs of these glycans, in which the 5′ and/or 5″ hydroxyl groups are replaced with fluoro, methoxy, azido, or amino groups are potential inhibitors of the α-(1 → 5) AraT's involved in mycobacterial arabinan assembly. In this paper, we report the synthesis of a panel of such oligosaccharides, **9**–**20**.



3 **5**

Figure 1. Example of an AraT-catalyzed reaction.



6, X = OH
9, X = F
12, X = OCH_3
15, X = N_3
18, X = NH_2

7, X = OH
10, X = F
13, X = OCH_3
16, X = N_3
19, X = NH_2

8, X = OH
11, X = F
14, X = OCH_3
17, X = N_3
20, X = NH_2

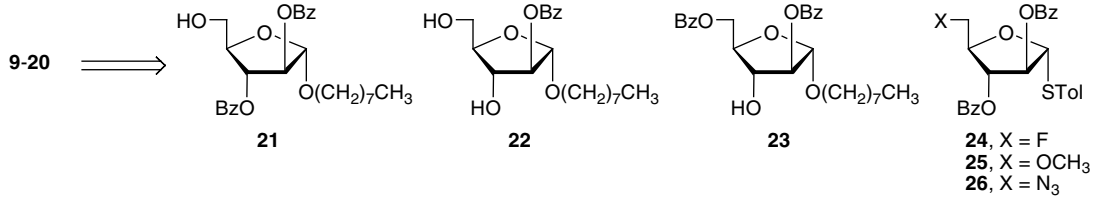
2. Results and discussion

In designing synthetic routes to the targets, we chose an approach in which the oligosaccharides were assembled using donors containing the desired functional group. Thus, six building blocks were required (Fig. 2): three acceptor species (**21**–**23**) and three thioglycoside donors (**24**–**26**).

2.1. Synthesis of monosaccharide building blocks 21–26

Compounds **21**–**23** were synthesized as previously reported,[43] starting from octyl α-D-arabinofuranoside.[44] The preparation of **24**–**26** was carried out as illustrated in Scheme 1.

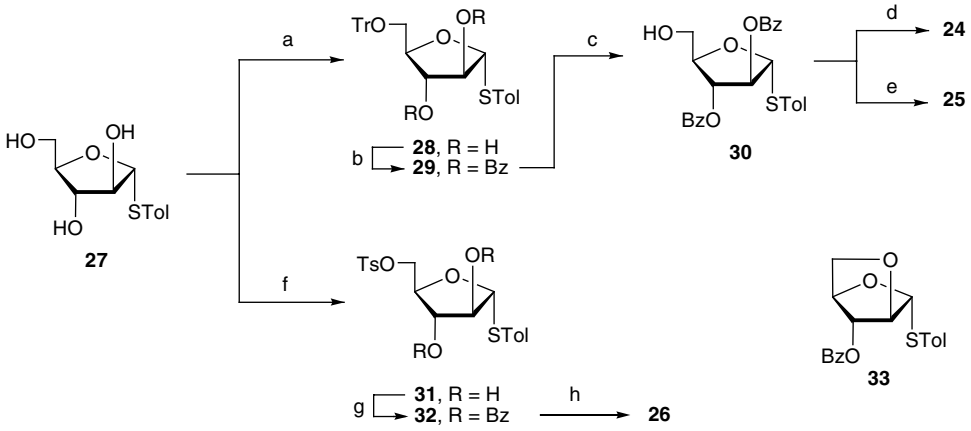
The donors **24** and **25** were synthesized via a common route. First, a conventional tritylation–benzoylation protocol was used to convert the known[45] thioglycoside **27** into **29** in 55% yield over the two steps. The trityl group was then cleaved in 86% yield to provide alcohol **30**. Reaction of **30** with diethylaminosulfur trifluoride (DAST) gave **24** in 60% yield. Incorporation of the fluorine was readily apparent from NMR spectroscopy. In the ^{1}H NMR spectrum for **24**, the resonances for each of the diastereotopic hydrogens on C-5 appeared as a doublet of doublet of doublets, with $^3J_{H,F}$ magnitudes of 46.5 and 47.6 Hz. Furthermore, in the ^{13}C NMR spectrum, the resonance for C-5 appeared as a doublet with $^1J_{C,F} = 173.3$ Hz. Long-range couplings to the resonances for C-4 ($^2J_{C,F} = 18.6$ Hz) and C-3



21 **22** **23**

24, X = F
25, X = OCH_3
26, X = N_3

Figure 2. Monosaccharide building blocks required for the assembly of **9**–**20**.



Scheme 1. (a) TrCl, DMAP, pyridine, CH_2Cl_2, rt, 65%. (b) BzCl, pyridine, rt, 85%. (c) *p*-TsOH, CH_3OH, GH_2Cl_2, rt, 86%. (d) DAST, CH_2Cl_2, −40 °C → rt, 60%. (e) $(CH_3)_3SiCHN_2$, HBF_4, CH_2Cl_2, 76%. (f) TsCl, DMAP, pyridine, CH_2Cl_2, rt, 58%. (g) BzCl, pyridine, rt, 84%. (h) NaN_3, 18-crown-6, DMF, 50 °C, 91%.

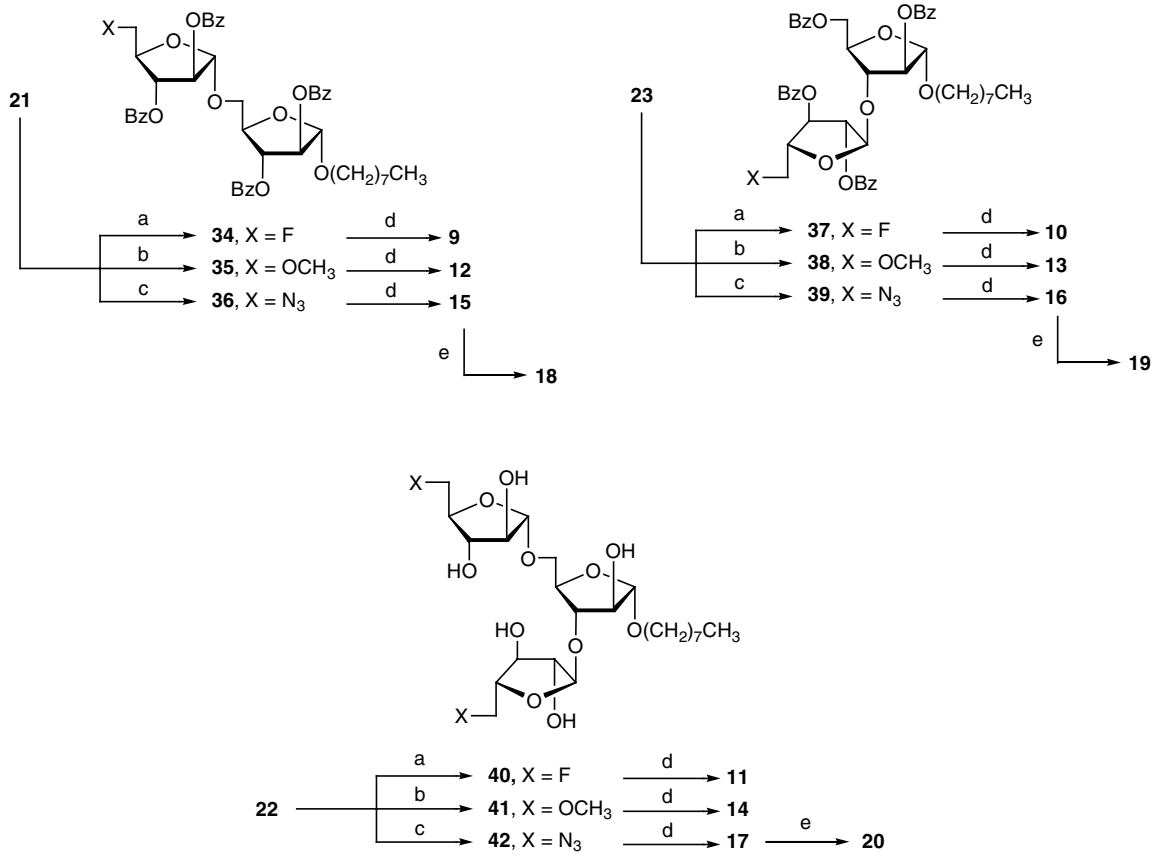
($^3J_{C,F} = 6.5$ Hz) were also apparent. We also explored using tosylate **32** (see preparation below) in the synthesis of the fluorosugar donor **24**. However, reaction of **32** with *n*-Bu_4NF, yielded only low yields of fluorinated products. The major product isolated had spectral data consistent with its structure being *p*-toluyl 2,5-anhydro-3-*O*-benzoyl-1-thio-α-D-arabinofuranoside (**33**).

Initial attempts to prepare the methoxy donor **25** by base-promoted methylation of **30** failed due to acyl group migration during the reaction, as might have been expected. Methylation under acidic conditions was therefore explored and found to be successful. Thus, reaction of **30** with TMS–diazomethane and fluoroboric acid afforded a 76% yield of the desired methylated compound, **25**. The resonances for the methyl group introduced in this reaction appeared as singlet at 3.48 ppm in the ^{1}H NMR spectrum and at 59.64 ppm in the ^{13}C NMR spectrum.

The preparation of the azidosugar donor, **26**, involved the selective tosylation of the hydroxyl group in **27**, followed by benzoylation, to afford in two steps and in 49% overall yield, tosylate **32**. Reaction of **32** with sodium azide at 50 °C in DMF provided a 91% yield of **26**. In the ^{13}C NMR spectrum, the resonance for C-5 appeared at 51.62 ppm as would be expected for a primary alkyl azide. In addition, both C-5 hydrogens appeared as doublet of doublets at 3.79 and 3.67 ppm, considerably upfield of where the resonances for these hydrogens in **32** are found (4.51 and 4.45 ppm). Further support for the structure of the molecule was obtained from the IR spectrum of **26**, which showed a peak at 2100.9 cm^{-1} resulting from the N=N=N asymmetric stretch of the azide.[46]

2.2. Synthesis of oligosaccharides 9–20

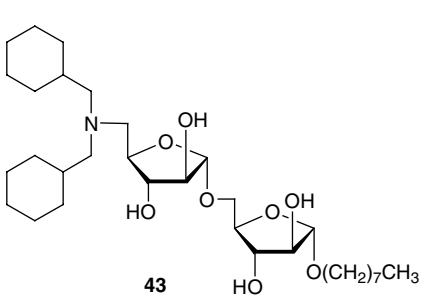
Having developed routes for the preparation of all of the monosaccharide building blocks, we proceeded to assemble them into oligosaccharides as illustrated in Scheme 2. All glycosylations were carried out in dichloromethane at 0 °C using *N*-iodosuccinimide and silver triflate activation of the thioglycoside donors. The yields in the glycosylations ranged from 68–97%, and the stereochemistry at the anomeric center in



Scheme 2. (a) **24**, *N*-iodosuccinimide, $AgOSO_2CF_3$, CH_2Cl_2, 0 °C, 89% (for **21**), 92% (for **23**), 81% (for **22**). (b) **25**, *N*-iodosuccinimide, $AgOSO_2CF_3$, CH_2Cl_2, 0 °C, 94% (for **21**), 97% (for **23**), 93% (for **22**). (c) **26**, *N*-iodosuccinimide, $AgOSO_2CF_3$, CH_2Cl_2, 0 °C, 88% (for **21**), 84% (for **23**), 68% (for **22**). (d) $NaOCH_3$, CH_3OH, rt, 75% (for **34**), 82% (for **35**), 97% (for **36**), 75% (for **37**), 82% (for **38**), 87% (for **39**), 90% (for **40**), 90% (for **41**), 87% (for **42**). (e) Ph_3P, H_2O, THF, rt, 73% (for **15**), 83% (for **16**), 83% (for **17**).

the resulting products (**34**–**42**) was determined through the use of ^{1}H and ^{13}C NMR spectroscopy. In all cases, the anomeric hydrogens of the newly introduced sugar residues appeared as a singlet, or small doublet ($^{3}J_{H1,H2} < 2$ Hz), which is diagnostic of the α-arabinofuranosyl stereochemistry.[47] Also consistent was the chemical shift of the anomeric carbons, which were in the range of 105–107 ppm.[47] In all cases, the characteristic NMR signals for the modified sugar residues that were apparent in the spectra of the monosaccharide donors, were also present in the oligosaccharide spectra. Debenzoylation of **34**–**42** was achieved by treatment with sodium methoxide to afford the target compounds **9**–**17** in 75–97% yield. Subsequent treatment of the azidosugar derivatives **15**, **16**, and **17** with triphenylphosphine in water afforded the amino sugars **18**, **19**, and **20** in 73%, 83%, and 83% yields, respectively. When each of **18**–**20** were spotted on a TLC plate and then treated with ninhydrin and heated, a red spot resulted, thus supporting the presence of an amino group in these compounds. Furthermore, in the ^{13}C NMR spectra the resonances for C-5′ and C-5″ in **18**–**20** were found between 41 and 44 ppm, as would be expected for a carbon atom attached to a primary amino group. Reduction of the azido groups could also be done by hydrogenation; however, the yields were generally lower.

In summary, we describe herein the synthesis of a panel of oligosaccharides containing C-5-modified arabinofuranosyl residues. The route used for the synthesis of the target compounds involved the preparation of three C-5-modified arabinofuranosyl thioglycosides and their subsequent coupling to the appropriate acceptors. Investigations on the ability of these compounds to inhibit mycobacterial arabinosyltransferases and to prevent the growth of mycobacteria are ongoing and will be reported in the future. With regard to these biochemical investigations, it is worth noting that while this paper was under review, a report[48] appeared in which it was demonstrated that disaccharide **18** did not inhibit mycobacterial arabinosyltransferases nor did it prevent the growth of mycobacteria. Interestingly, however, a bis(cyclohexylmethyl)amino derivative **43** both inhibited the enzyme and prevented mycobacterial growth.



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3. Experimental

3.1. General methods

Reactions were carried out in oven-dried glassware. Solvents were distilled from appropriate drying agents before use. Unless stated otherwise, all reactions were carried out under a positive pressure of argon and were monitored by TLC on Silica Gel 60 F_{254} (0.25 mm, E. Merck). Spots were detected under UV light or by charring with 10% H_2SO_4, in EtOH. Unless otherwise indicated, all column chromatography was performed on Silica Gel 60 (40–60 μM). Iatrobeads refers to a beaded silica gel 6RS-8060, which is manufactured by Iatron Laboratories (Tokyo). The ratio between silica gel and crude product ranged from 100 to 50:1 (w/w). Optical rotations were measured at 22 ± 2 °C. ^{1}H NMR spectra were recorded at 250, 400, or 500 MHz, and chemical shifts are referenced to either Me_4Si (0.0, $CDCl_3$) or HOD (4.78, D_2O and CD_3OD). ^{13}C NMR spectra were recorded at 63, 100 or 125 MHz, and ^{13}C chemical shifts were referenced to internal $CDCl_3$ (77.23, $CDCl_3$), external dioxane (67.40, D_2O) or CD_3OD (48.9, CD_3OD). Electrospray-ionization mass spectra (ESIMS) were recorded on samples suspended in mixtures of THF with CH_3OH and added NaCl.

3.2. Octyl 5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 5)-α-D-arabinofuranoside (9)

To a solution of **34** (40 mg, 0.05 mmol) in dry CH_3OH (10 mL), was added a 0.1 M solution of $NaOCH_3$ in CH_3OH until the pH of the solution was 11. The reaction mixture was stirred overnight and then neutralized with a few drops of HOAc. The solution was concentrated, and the residue was purified by chromatography (6:1 CH_2Cl_2–CH_3OH) to give **9** (15 mg, 75%) as a colorless oil: R_f 0.47 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +110.8° (*c* 0.9, CH_3OH); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 5.10 (s, 1H), 4.90 (s, 1H), 4.83 (dd, 2H, *J* 3.3, 45.6 Hz), 4.40–4.25 (m, 2H), 4.10–3.60 (m, 7H), 3.33–3.49 (m, 1H), 1.59–1.53 (m, 2H), 1.31–1.29 (m, 10H), 0.89–0.87 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 107.17, 106.74, 84.62 (d, *J* 17.8 Hz), 83.07, 82.60 (d, *J* 169.1 Hz), 82.04 (d, *J* 6.7 Hz), 81.69, 76.51, 75.31, 67.60, 66.39, 31.78, 29.73, 29.61, 29.57, 26.34, 22.81, 14.29; ESIMS: *m*/*z* calcd for $[C_{18}H_{33}FO_8]Na^+$: 419.2053. Found: 419.2021.

3.3. Octyl 5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 3)-α-D-arabinofuranoside (10)

Disaccharide **37** (40 mg, 0.05 mmol) dissolved in dry CH_3OH (10 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (10:1 CH_2Cl_2–CH_3OH) to give **10** (15 mg, 75%) as a colorless

oil: R_f 0.58 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +89.6° (*c* 0.8, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.12 (s, 1H), 4.94 (s, 1H), 4.67–4.49 (m, 2H), 4.16 (s, 1H), 4.15–3.99 (m, 3H), 3.95 (dd, 1H, *J* 3.5, 6.5 Hz), 3.79–3.73 (m, 2H), 3.71–3.63 (m, 2H), 3.48–3.43 (m, 1H), 1.56–1.54 (m, 2H), 1.27–1.24 (m, 10H), 0.84–0.81 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 107.81, 107.75, 82.86 (d, *J* 7.8 Hz), 82.61 (d, *J* 167.1 Hz), 82.48 (d, *J* 17.5 Hz), 81.59, 80.41, 76.00, 75.59, 68.35, 61.04, 32.01, 29.48, 29.46, 29.44, 26.13, 22.79, 14.08; ESIMS: *m*/*z* calcd for $[C_{18}H_{33}FO_8]Na^+$: 419.2052. Found: 419.2034.

3.4. Octyl 5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 3)-[5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 5)]-α-D-arabinofuranoside (11)

Trisaccharide **40** (50 mg, 0.05 mmol) dissolved in dry CH_3OH (5 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (6:1 CH_2Cl_2–CH_3OH) to give **11** (24 mg, 90%) as a colorless oil: R_f 0.54 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +67.9° (*c* 1.0, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.17 (s, 1H), 5.09 (d, 1H, *J* 1.8 Hz), 4.92 (s, 1H), 4.80 (dd, 2H, *J* 3.3, 45.6 Hz), 4.45–4.05 (m, 7H), 3.90–3.65 (m, 6H), 3.66–3.54 (m, 1H), 3.41–3.34 (m, 1H), 1.59–1.53 (m, 2H), 1.32–1.31 (m, 10H), 0.88–0.85 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 107.54, 107.21, 106.79, 84.01, 83.04 (d, *J* 167.8 Hz), 83.23 (d, *J* 16.9 Hz), 82.77 (d, *J* 166.7 Hz), 82.61 (d, *J* 17.5 Hz), 81.96 (d, *J* 6.5 Hz), 81.77 (d, *J* 7.1 Hz), 81.59, 80.44, 76.45, 67.90, 66.23, 61.05, 31.77, 29.73, 29.69, 29.61, 26.35, 22.81, 14.30; ESIMS: *m*/*z* calcd for $[C_{23}H_{40}F_2O_{11}]Na^+$: 553.2431. Found: 553.2449.

3.5. Octyl 5-*O*-methyl-α-D-arabinofuranosyl-(1 → 5)-α-D-arabinofuranoside (12)

Disaccharide **35** (80 mg, 0.09 mmol) dissolved in dry CH_3OH (10 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (6:1 CH_2Cl_2–CH_3OH) to give **12** (30 mg, 82%) as a colorless oil: R_f 0.42 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +98.6° (*c* 0.7, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 5.03 (s, 1H), 4.97 (s, 1H), 4.21–4.19 (m, 1H), 4.16–4.14 (m, 1H), 4.09–3.94 (m, 4H), 3.73–3.67 (m, 2H), 3.63–3.57 (m, 2H), 3.43 (s, 3H), 3.45–3.39 (m, 1H), 3.31–3.28 (m, 1H), 1.58–1.55 (m, 2H), 1.28–1.27 (m, 10H), 0.89–0.86 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 108.99, 108.19, 86.34, 85.29, 80.28, 79.86, 78.65, 78.18, 72.61, 68.19, 66.98, 59.88, 32.21, 29.88, 29.73, 29.62, 26.51, 23.04, 14.49; ESIMS: *m*/*z* calcd for $[C_{19}H_{36}O_9]Na^+$: 431.2252. Found: 431.2256.

3.6. Octyl 5-*O*-methyl-α-D-arabinofuranosyl-(1 → 3)-α-D-arabinofuranoside (13)

Disaccharide **38** (45 mg, 0.06 mmol) dissolved in dry CH_3OH (10 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (6:1 CH_2Cl_2–CH_3OH) to give **13** (20 mg, 82%) as a colorless oil: R_f 0.33 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +74.8° (*c* 1.2, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 5.15 (s, 1H), 4.94 (s, 1H), 4.20–4.19 (m, 1H), 4.15–4.14 (m, 1H), 4.10 (s, 1H), 4.03–4.01 (m, 3H), 3.86–3.84 (m, 4H), 3.60 (d, 1H, *J* 2.0 Hz), 3.43 (s, 3H), 3.40–3.38 (m, 1H), 1.56–1.53 (m, 2H), 1.27 (m, 10H), 0.89–0.86 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 109.40, 108.65, 87.10, 84.33, 83.96, 79.57, 79.03, 78.15, 72.38, 68.50, 62.23, 59.86, 32.21, 29.80, 29.72, 29.65, 26.41, 23.04, 14.48; ESIMS: *m*/*z* calcd for $[C_{19}H_{36}O_9]Na^+$: 431.2252. Found: 431.2256.

3.7. Octyl 5-*O*-methyl-α-D-arabinofuranosyl-(1 → 3)-[5-*O*-methyl-α-D-arabinofuranosyl-(1 → 5)]-α-D-arabinofuranoside (14)

Trisaccharide **41** (35 mg, 0.03 mmol) dissolved in dry CH_3OH (5 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (10:1 CH_2Cl_2–CH_3OH) to give **14** (15 mg, 90%) as a colorless oil: R_f 0.23 (10:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +99.7° (*c* 0.9, CH_3OH); ^1H NMR (500 MHz, $CDCl_3$): δ_H, 5.13 (s, 1H), 5.04 (s, 1H), 4.93 (s, 1H), 4.24–4.22 (m, 2H), 4.18–4.17 (m, 1H), 4.16–4.15 (m, 1H), 4.09 (s, 1H), 4.06–4.04 (m, 2H), 4.02–3.98 (m, 6H), 3.95–3.94 (m, 1H), 3.74–3.68 (m, 2H), 3.66–3.63 (m, 1H), 3.39 (s, 3H), 3.38 (s, 3H), 1.52–1.46 (m, 2H), 1.23–1.21 (m, 10H), 0.83–0.80 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ_C, 109.36, 108.74, 108.01, 87.33, 86.68, 84.56, 82.63, 79.66, 79.23, 78.58, 78.10, 78.01, 72.34, 72.11, 68.21, 66.40, 59.73, 59.72, 32.02, 29.58, 28.52, 29.46, 26.21, 22.86, 14.32; ESIMS: *m*/*z* calcd for $[C_{25}H_{46}O_{13}]Na^+$: 577.2831. Found: 577.2828.

3.8. Octyl 5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 5)-α-D-arabinofuranoside (15)

Disaccharide **36** (120 mg, 0.14 mmol) dissolved in dry CH_3OH (10 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (10:1 CH_2Cl_2–CH_3OH) to give **15** (57 mg, 97%) as a colorless oil: R_f 0.33 (10:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +79.4° (*c* 0.6, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.05 (s, 1H), 4.95 (d, 1H, *J* 1.6 Hz), 4.14–4.11 (m, 1H), 4.08–4.07 (m, 2H), 4.01–4.00 (m, 1H), 3.96–3.91 (m, 2H), 3.85–3.82 (m, 1H), 3.75–3.63 (m, 3H), 3.53–3.41 (m, 2H), 1.57–1.54 (m, 2H), 1.25–1.23 (m, 10H), 0.82–0.80 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 106.71, 106.41, 81.44, 80.84,

80.17, 80.10, 76.57, 75.79, 67.68, 66.03, 50.72, 30.39, 27.92, 27.87, 27.73, 24.48, 21.28, 12.64; ESIMS: m/z calcd for $[C_{18}H_{33}N_3O_8]Na^+$: 442.2160. Found: 442.2186.

3.9. Octyl 5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-α-D-arabinofuranoside (16)

Disaccharide **39** (50 mg, 0.06 mmol) dissolved in dry CH_3OH (10 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (10:1 CH_2Cl_2–CH_3OH) to give **16** (22 mg, 87%) as a colorless oil: R_f 0.43 (10:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +99.7° (*c* 0.9, CH_3OH); ^1H NMR (500 MHz, D_2O): δ_H, 5.11 (d, 1H, *J* 1.3 Hz), 4.98 (s, 1H), 4.16–4.15 (m, 1H), 4.12–4.09 (m, 1H), 4.08–4.04 (m, 2H), 3.96–3.95 (m, 1H), 3.89 (dd, 1H, *J* 2.8, 6.3 Hz), 3.78 (dd, 1H, *J* 3.4, 12.3 Hz), 3.73–3.60 (m, 3H), 3.55–3.49 (m, 1H), 3.45 (dd, 1H, *J* 6.4, 13.6 Hz), 1.67–1.55 (m, 2H), 1.25–1.07 (m, 10H), 0.87–0.81 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 107.75, 107.57, 83.51, 83.09, 82.55, 81.58, 79.67, 77.73, 68.47, 61.44, 51.84, 31.49, 28.98, 28.83, 28.76, 25.65, 22.41, 13.79; ESIMS: m/z calcd for $[C_{18}H_{33}N_3O_8]Na^+$: 442.2160. Found: 442.2164.

3.10. Octyl 5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-[5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 5)]-α-D-arabinofuranoside (17)

Trisaccharide **42** (80 mg, 0.07 mmol) dissolved in dry CH_3OH (5 mL) was debenzoylated with 0.1 M $NaOCH_3$ in CH_3OH as described for the synthesis of **9**. The product was purified by chromatography (10:1 CH_2Cl_2–CH_3OH) to give **17** (35 mg, 87%) as a colorless oil: R_f 0.51 (10:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +84.9° (*c* 0.9, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.20 (d, 1H, *J* 1.6 Hz), 5.15 (d, 1H, *J* 1.4 Hz), 5.08 (s, 1H), 4.33–4.32 (m, 1H), 4.25–4.23 (m, 1H), 4.22–4.19 (m, 1H), 4.18–4.14 (m, 3H), 4.09–4.07 (m, 1H), 4.03–3.96 (m, 3H), 3.90–3.89 (m, 1H), 3.78–3.71 (m, 3H), 3.64–3.59 (m, 1H), 3.57–3.53 (m, 2H), 1.65–1.61 (m, 2H), 1.34–1.25 (m, 10H), 0.95–0.89 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 107.95, 107.75, 107.53, 83.52, 82.73, 82.58, 81.94, 81.80, 81.61, 81.36, 79.65, 77.89, 77.71, 68.48, 51.95, 51.94, 31.50, 28.97, 28.85, 28.69, 25.63, 22.42, 13.80; ESIMS: m/z calcd for $[C_{23}H_{40}N_6O_{11}]Na^+$: 599.2647. Found: 599.2647.

3.11. Octyl 5-amino-5-deoxy-α-D-arabinofuranosyl-(1 → 5)-α-D-arabinofuranoside (18)

A solution of **15** (30 mg, 0.07 mmol) and Ph_3P (24 mg, 0.09 mmol) in THF (5 mL) containing a few drops of water was stirred for 24 h. The solution was then concentrated and the product purified by chromatography (1:1 CH_2Cl_2–CH_3OH with 2% Et_3N) on Iatrobeads to give **18** (20 mg, 73%): R_f 0.12 (3:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +76.4° (*c* 0.6, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.09 (s, 1H), 4.96 (d, 1H, *J* 1.8 Hz), 4.23–4.19 (m, 1H), 4.12–4.08 (m, 2H), 4.01 (dd, 1H, *J* 1.9, 3.7 Hz), 3.95–3.89 (m, 2H), 3.83 (dd, 1H, *J* 5.6, 11.5 Hz), 3.74 (dd, 1H, *J* 3.13, 11.5 Hz), 3.71–3.65 (m, 1H), 3.58–3.48 (m, 1H), 3.35 (dd, 1H, *J* 3.2, 13.4 Hz), 3.15 (dd, 1H, *J* 6.6, 13.4 Hz), 3.20–3.12 (m, 1H), 1.57–1.53 (m, 2H), 1.32–1.19 (m, 10H), 0.82–0.79 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 108.18, 107.66, 82.08, 81.20, 80.78, 80.66, 78.45, 76.88, 69.00, 67.16, 41.62, 31.47, 28.98, 28.76, 25.55, 23.65, 22.39, 13.79; ESIMS: m/z calcd for $[C_{18}H_{35}NO_8]Na^+$: 416.2255. Found: 416.2258.

3.12. Octyl 5-amino-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-α-D-arabinofuranoside (19)

Disaccharide **16** (15 mg, 0.04 mmol) was reduced with Ph_3P (30 mg, 0.12 mmol) in THF (5 mL) containing a few drops of water as described for the synthesis of **18**. The product was purified by chromatography (2:1 CH_2Cl_2–CH_3OH with 2% Et_3N) on Iatrobeads to give **19** (25 mg, 83%) as a white solid: R_f 0.15 (2:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +77.9° (*c* 0.6, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 4.93 (s, 1H), 4.74 (s, 1H), 3.94–3.89 (m, 2H), 3.87–3.86 (m, 1H), 3.85–3.82 (m, 1H), 3.76 (dd, 1H, *J* 2.5, 5.7 Hz), 3.66 (dd, 1H, *J* 2.6, 5.1 Hz), 3.54 (dd, 1H, *J* 3.4, 12.3 Hz), 3.47–3.41 (m, 2H), 3.31–3.25 (m, 1H), 3.10 (dd, 1H, *J* 3.2, 13.4 Hz), 2.90 (dd, 1H, *J* 6.6, 13.4 Hz), 1.32–1.28 (m, 2H), 1.06–0.94 (m, 10H), 0.57–0.54 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 109.61, 109.50, 84.86, 84.14, 82.76, 82.57, 81.35, 80.14, 70.49, 63.09, 43.35, 31.47, 28.98, 28.76, 25.55, 23.65, 22.39, 13.79; ESIMS: m/z calcd for $[C_{18}H_{35}NO_8]Na^+$: 416.2255. Found: 416.2225.

3.13. Octyl 5-amino-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-[5-amino-5-deoxy-α-D-arabinofuranosyl-(1 → 5)]-α-D-arabinofuranoside (20)

Trisaccharide **17** (37 mg, 0.05 mmol) was reduced with Ph_3P (33 mg, 0.12 mmol) in THF (5 mL) containing a few drops of water as described for the synthesis of **18**. The product was purified by chromatography (2:1 CH_2Cl_2–CH_3OH with 2% Et_3N) on Iatrobeads to give **20** (25 mg, 83%) as a white solid: R_f 0.11 (6:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ +78.9° (*c* 1.3, CH_3OH); ^1H NMR (400 MHz, D_2O): δ_H, 5.15 (s, 1H), 5.09 (s, 1H), 4.99 (s, 1H), 4.22–4.17 (m, 3H), 4.16–4.09 (m, 3H), 3.98 (dd, 1H, *J* 2.0, 5.3 Hz), 3.89 (dd, 2H, *J* 2.7, 5.1 Hz), 3.85 (dd, 1H, *J* 5.9, 11.3 Hz), 3.79 (dd, 1H, *J* 3.0, 11.3 Hz), 3.69–3.64 (m, 1H), 3.54–3.48 (m, 1H), 3.29–3.19 (m, 2H), 3.10–3.05 (m, 2H), 1.55–1.50 (m, 2H), 1.31–1.18 (m, 10H), 0.82–0.78 (m, 3H); ^{13}C NMR (100 MHz, D_2O): δ_C, 108.21, 107.89, 107.82, 82.78, 81.92, 81.65, 81.08, 80.97, 80.78, 79.88, 78.35, 78.21, 68.67, 67.30, 41.76, 41.72,

31.46, 28.92, 28.77, 25.69, 23.66, 22.39, 13.79; ESIMS: m/z calcd for $[C_{23}H_{44}N_2O_{11}]Na^+$: 547.2837. Found: 547.2813.

3.14. *p*-Toluyl 2,3-di-*O*-benzoyl-5-deoxy-5-fluoro-1-thio-α-D-arabinofuranoside (24)

To a solution of **30** (312 mg, 0.67 mmol) in CH_2Cl_2 (15 mL) kept at −40 °C was added DAST (0.17 mL, 1.34 mmol). The reaction mixture was slowly warmed to room temperature and stirred for 3 h. Then, the reaction mixture was poured over water and extracted three times with CH_2Cl_2. After drying (Na_2SO_4), the organic solution was filtered and concentrated, and the product was purified by chromatography (4:1 hexanes–EtOAc) to give **24** (187 mg, 60%) as a syrup: R_f 0.72 (2:1 hexanes–EtOAc); $[\alpha]_D$ +76.5° (*c* 0.7, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 8.16–8.14 (m, 2H), 8.08–8.06 (m, 2H), 7.64–7.60 (m, 2H), 7.53–7.44 (m, 6H), 7.17–7.15 (m, 2H), 5.80–5.79 (s, 1H), 5.76 (d, *J* 1.3 Hz), 5.57 (ddd, 1H, *J* 0.9, 1.3, 4.5 Hz), 4.89 (ddd, 1H, *J* 3.9, 10.3, 46.5 Hz), 4.79 (ddd, 1H, *J* 2.5, 10.3, 47.6 Hz), 4.65 (dddd, 1H, *J* 2.5, 3.9, 4.5, 26.4 Hz), 2.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 165.88, 165.44, 138.27, 133.88, 133.79, 132.87, 130.20, 130.10, 130.07, 129.91, 129.16, 129.12, 128.78, 128.70, 91.86, 82.31 (d, *J* 18.6 Hz), 81.84 (d, *J* 173.3 Hz), 81.63, 77.21 (d, *J* 6.5 Hz), 21.30; ESIMS: m/z calcd for $[C_{26}H_{23}FO_5S]Na^+$: 489.1142. Found: 489.1128.

3.15. *p*-Toluyl 2,3-di-*O*-benzoyl-5-*O*-methyl-1-thio-α-D-arabinofuranoside (25)

To a solution of **30** (213 mg, 0.45 mmol) in CH_2Cl_2 (5 mL) kept at 0 °C, was added a 48% solution of HBF_4 in H_2O (0.08 mL, 0.49 mmol), and then a 1.8 M solution of $TMSCHN_2$ in hexanes (0.28 mL) was added, followed by three more aliquots added every 20 min (0.14, 0.07, and 0.07, 0.49 mmol total). After stirring for 50 min at 0 °C, the reaction mixture was poured into water (10 mL) and extracted three times with CH_2Cl_2 (30 mL). After drying (Na_2SO_4), the organic solution was filtered and concentrated, and the product was purified by chromatography (6:1 hexanes–EtOAc) to give **25** (164 mg, 76%) as a syrup: R_f 0.29 (6:1 hexanes–EtOAc); $[\alpha]_D$ +98.5° (*c* 0.7, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 8.17–8.14 (m, 2H), 8.11–8.06 (m, 2H), 7.64–7.57 (m, 2H), 7.35–7.44 (m, 6H), 7.16–7.13 (m, 2H), 5.80–5.79 (m, 1H), 5.73 (dd, 1H, *J* 1.6, 1.6 Hz), 5.60–5.58 (m, 1H), 4.71–4.67 (m, 1H), 3.86 (d, 1H, *J* 1.3 Hz), 3.85 (d, 1H, *J* 2.5 Hz), 3.48 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 165.72, 165.44, 137.95, 137.88, 133.65, 133.62, 132.72, 132.42, 130.18, 130.16, 130.09, 130.01, 129.91, 129.31, 129.27, 129.19, 128.64, 128.59, 128.56, 91.85, 82.43, 82.25, 78.17, 71.83, 59.64, 21.22; ESIMS: m/z calcd for $[C_{27}H_{26}O_6S]Na^+$: 501.1342. Found: 501.1359.

3.16. *p*-Toluyl 5-azido-2,3-di-*O*-benzoyl-5-deoxy-1-thio-α-D-arabinofuranoside (26)

A solution of **32** (500 mg, 0.81 mmol), NaN_3 (157 mg, 2.43 mmol) and 18-crown-6 (0.5 mL, 2.43 mmol) in DMF (10 mL) was heated at 50 °C overnight. The reaction mixture was cooled and concentrated to a colorless syrup that was purified by chromatography (4:1 hexanes–EtOAc) to give **26** (340 mg, 91%) as an oil: R_f 0.84 (2:1 hexanes–EtOAc); $[\alpha]_D$ +112.6° (*c* 0.9, $CHCl_3$); ^{1}H NMR (250 MHz, $CDCl_3$): δ_H, 8.13–8.05 (m, 4H), 7.58–7.53 (m, 2H), 7.48–7.39 (m, 6H), 7.14–7.11 (m, 2H), 5.78–5.77 (m, 1H), 5.73 (d, 1H, *J* 1.4 Hz), 5.48–5.45 (m, 1H), 4.68–4.63 (m, 1H), 3.79 (dd, 1H, *J* 3.1, 13.3 Hz), 3.67 (dd, 1H, *J* 4.8, 13.3 Hz), 2.31 (s, 3H); ^{13}C NMR (63 MHz, $CDCl_3$): δ_C, 165.79, 165.36, 138.25, 133.78, 133.75, 132.91, 132.64, 130.11, 130.02, 129.97, 129.76, 129.07, 129.07, 129.06, 128.69, 128.65, 91.92, 82.24, 78.65, 51.62, 21.22; ESIMS: m/z calcd for $[C_{26}H_{23}N_3O_5S]Na^+$: 512.1251. Found: 512.1266.

3.17. *p*-Toluyl 5-*O*-triphenylmethyl-1-thio-α-D-arabinofuranoside (28)

To a solution of **27**[45] (840 mg, 3.28 mmol) in dry pyridine (15 mL) and dry CH_2Cl_2 (5 mL) was added dropwise triphenylmethyl chloride (1.5 g, 5.6 mmol) and DMAP (488 mg, 4 mmol). The reaction mixture was stirred overnight, then diluted with CH_2Cl_2 (15 mL) and washed successively with 0.1 M HCl (20 mL), water (20 mL), and brine (20 mL). After drying (Na_2SO_4), the organic solution was filtered and concentrated to give **33** (1.07 g, 65%) as an oil, which was used without purification in the next step: R_f 0.76 (6:1 CH_2Cl_2–CH_3OH).

3.18. *p*-Toluyl 2,3-di-*O*-benzoyl-5-*O*-triphenylmethyl-1-thio-α-D-arabinofuranoside (29)

To a solution of crude **28** (1.07 g, 2.15 mmol) in dry pyridine (15 mL) was added dropwise benzoyl chloride (1.1 mL, 10 mmol). The reaction mixture was stirred overnight, then diluted with CH_2Cl_2 (20 mL) and washed successively with 0.1 M HCl (30 mL), water (15 mL), and brine (15 mL). After drying (Na_2SO_4), the organic solution was filtered and concentrated. The residue was purified by chromatography (6:1 hexanes–EtOAc) to give **29** (1.29 g, 85%) as an oil: R_f 0.36 (6:1 hexanes–EtOAc); $[\alpha]_D$ +110.3° (*c* 0.7, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 8.10–8.08 (m, 2H), 7.94–7.91 (m, 2H), 7.56–7.52 (m, 2H), 7.49–7.44 (m, 10H), 7.36–7.34 (m, 2H), 7.24–7.12 (m, 9H), 7.10–7.09 (m, 2H), 5.71 (d, 1H, *J* 1.9 Hz), 5.67–5.65 (m, 1H), 5.64 (dd, 1H, *J* 1.9, 1.9 Hz), 4.70 (ddd, 1H, *J* 4.9, 4.9, 5.4 Hz), 3.53 (dd, 1H, *J* 5.4, 10.0 Hz), 3.47 (dd, 1H, *J* 4.9, 10.0 Hz), 2.30 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 165.53,

165.43, 143.93, 138.11, 133.59, 133.07, 130.07, 130.23, 130.18, 130.11, 129.97, 129.51, 129.27, 128.92, 128.64, 128.11, 128.08, 128.01, 127.41, 127.22, 127.16, 91.73, 87.14, 82.55, 82.18, 78.27, 63.65, 21.33; ESIMS: m/z calcd for $[C_{45}H_{38}O_6S]Na^+$: 729.2281. Found: 729.2299.

3.19. *p*-Toluyl 2,3-di-*O*-benzoyl-1-thio-α-D-arabinofuranoside (30)

To a solution of **29** (181 mg, 0.25 mmol) in 3:1 CH_3OH–CH_2Cl_2 (10 mL) was added *p*-toluenesulfonic acid (54 mg, 0.28 mmol). The reaction mixture was stirred overnight, then Et_3N (0.1 mL) was added. The solution was concentrated, and the residue was purified by chromatography (8:1 hexanes–EtOAc) to give **30** (100 mg, 86%) as an oil: R_f 0.21 (8:1 hexanes–EtOAc); $[\alpha]_D$ +98.6° (*c* 0.8, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 8.13–8.10 (m, 2H), 8.04–8.02 (m, 2H), 7.61–7.54 (m, 2H), 7.49–7.41 (m, 6H), 7.14–7.12 (m, 2H), 5.72–5.71 (m, 2H), 5.54–5.52 (m, 1H), 4.57 (ddd, 1H, *J* 4.0, 4.0, 4.0 Hz), 4.03–3.99 (m, 2H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 166.14, 165.41, 138.33, 133.84, 133.80, 133.08, 130.20, 130.06, 130.04, 129.94, 129.22, 129.15, 128.75, 128.73, 91.95, 83.87, 82.35, 78.07, 62.16, 21.31; ESIMS: m/z calcd for $[C_{26}H_{24}O_6S]Na^+$: 487.1186. Found: 487.1208.

3.20. *p*-Toluyl 5-*O*-*p*-toluenesulfonyl-1-thio-α-D-arabinofuranoside (31)

To a solution of **27** (770 mg, 2.9 mmol) in dry pyridine (15 mL) and dry CH_2Cl_2 (5 mL) was added dropwise *p*-toluenesulfonyl chloride (830 mg, 4.3 mmol) and DMAP (177 mg, 1.45 mmol). The reaction mixture was stirred overnight, then diluted with CH_2Cl_2 (15 mL) and washed successively with 0.1 M HCl (20 mL), water (20 mL), and brine (20 mL). After drying (Na_2SO_4), the organic solution was filtered and concentrated. The residue was purified by chromatography (1:1 hexanes–EtOAc) to give **31** (700 mg, 58%) as an oil: R_f 0.28 (1:1 hexanes–EtOAc); $[\alpha]_D$ +87.6° (*c* 0.9, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 7.78–7.76 (m, 2H), 7.35–7.28 (m, 4H), 7.09–7.08 (m, 2H), 5.20–5.19 (m, 1H), 4.22 (s, 2H), 4.13–4.11 (m, 3H), 2.43 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 145.38, 137.99, 132.53, 132.41, 130.13, 129.95, 129.77, 128.18, 91.40, 81.46, 79.86, 76.74, 68.81, 21.82, 21.29; ESIMS: m/z calcd for $[C_{19}H_{22}O_6S_2]Na^+$: 433.0637. Found: 433.0632.

3.21. *p*-Toluyl 2,3-di-*O*-benzoyl-5-*O*-*p*-toluenesulfonyl-1-thio-α-D-arabinofuranoside (32)

To a solution of **31** (230 mg, 0.56 mmol) in dry pyridine (10 mL) was added dropwise benzoyl chloride (0.19 mL, 1.68 mmol). After 12 h, the mixture was diluted with CH_2Cl_2 (15 mL) and washed successively with 0.1 M HCl (20 mL), water (20 mL), and brine (20 mL). After drying (Na_2SO_4), the solution was filtered and concentrated. The residue was purified by chromatography (6:1 hexanes–EtOAc) to give **32** (290 mg, 84%) as an oil: R_f 0.23 (6:1 hexanes–EtOAc); $[\alpha]_D$ +102.4° (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 8.12–8.05 (m, 4H), 7.77–7.76 (m, 2H), 7.60–7.58 (m, 2H), 7.49–7.46 (m, 4H), 7.41–7.39 (m, 2H), 7.22–7.20 (m, 2H), 7.13–7.11 (m, 2H), 5.65 (s, 1H), 5.62 (s, 1H), 5.38 (d, 1H, *J* 4.2 Hz), 4.60 (ddd, 1H, *J* 3.4, 3.9, 4.4 Hz), 4.51 (dd, 1H, *J* 4.4, 10.9 Hz), 4.45 (dd, 1H, *J* 3.4, 10.9 Hz), 2.34 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 165.70, 165.39, 145.08, 138.29, 133.92, 133.91, 133.88, 132.87, 132.82, 130.35, 130.22, 130.17, 130.03, 129.97, 129.78, 129.46, 128.96, 128.75, 128.65, 128.23, 92.11, 81.74, 81.31, 77.92, 68.62, 21.77, 21.31; ESIMS: m/z calcd for $[C_{33}H_{30}O_8S_2]Na^+$: 641.1274. Found: 641.1278.

3.22. Octyl 2,3-di-*O*-benzoyl-5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 5)-2,3-di-*O*-benzoyl-α-D-arabinofuranoside (34)

A solution of **21**[43] (85 mg, 0.18 mmol), **24** (98 mg, 0.21 mmol) and powdered molecular sieves (4 Å, 100 mg) in dry CH_2Cl_2 (10 mL) was stirred at 0 °C for 10 min before *N*-iodosuccinimide (40 mg, 0.18 mmol) and silver triflate (15 mg, 0.06 mmol) were added. After stirring for 5 min at 0 °C, Et_3N (0.1 mL) was added. The reaction mixture was then diluted with CH_2Cl_2 (10 mL) and filtered through Celite. The filtrate was washed successively with a satd aq $Na_2S_2O_3$ (15 mL), water (15 mL), and brine (15 mL). After drying (Na_2SO_4), the organic phase was filtered and concentrated. The residue was purified by chromatography (4:1 hexanes–EtOAc) to give **34** (130 mg, 89%) as an oil: R_f 0.34 (4:1 hexanes–EtOAc); $[\alpha]_D$ +116.8° (*c* 0.9, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 8.13–8.07 (m, 6H), 8.00–7.98 (m, 2H), 7.65–7.60 (m, 2H), 7.58–7.55 (m, 1H), 7.54–7.44 (m, 7H), 7.35–7.30 (m, 2H), 5.71 (s, 1H), 5.66 (d, 1H, *J* 4.8 Hz), 5.56 (d, 1H, *J* 1.2 Hz), 5.51 (s, 1H), 5.48 (d, 1H, *J* 4.5 Hz), 5.27 (s, 1H), 4.86 (dd, 2H, *J* 3.2, 47.0 Hz), 4.80 (d, 1H, *J* 3.2 Hz), 4.65 (dddd, 1H, *J* 3.2, 3.2, 4.3, 25.8 Hz), 4.50–4.47 (m, 1H), 4.27 (dd, 1H, *J* 4.6, 11.2 Hz), 4.01 (dd, 1H, *J* 2.8, 11.2 Hz), 3.82–3.76 (m, 1H), 3.57–3.52 (m, 1H), 1.69–1.63 (m, 2H), 1.45–1.29 (m, 10H), 0.92–0.89 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 166.04, 165.87, 165.59, 165.31, 133.69, 133.63, 133.56, 133.52, 130.10, 130.05, 129.98, 129.50, 129.50, 129.34, 129.32, 129.13, 128.69, 128.68, 128.59, 128.50, 106.17, 105.74, 83.07, 82.19 (d, *J* 175.1 Hz), 82.62 (d, *J* 18.5 Hz), 82.03, 81.96 77.51, 77.11 (d, *J* 6.5 Hz), 67.60, 66.42, 31.99, 29.73, 29.58, 29.44, 26.35, 22.82, 14.26; ESIMS: m/z calcd for $[C_{46}H_{49}FO_{12}]Na^+$: 835.3100. Found: 835.3046.

3.23. Octyl 2,3-di-*O*-benzoyl-5-*O*-methyl-α-D-arabinofuranosyl-(1 → 5)-2,3-di-*O*-benzoyl-α-D-arabinofuranoside (35)

Disaccharide **35** was prepared from **21**[43] (43 mg, 0.09 mmol) and **25** (52 mg, 0.11 mmol) and powdered molecular sieves (4 Å, 100 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (50 mg, 0.22 mmol) and silver triflate (10 mg, 0.04 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) gave **35** (70 mg, 94%) as an oil: R_f 0.12 (4:1 hexanes–EtOAc); $[\alpha]_D$ +84.9° (*c* 0.7, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ_H, 8.00–7.96 (m, 4H), 7.94–7.93 (m, 2H), 7.88–7.86 (m, 2H), 7.53–7.48 (m, 2H), 7.44–7.41 (m, 1H), 7.39–7.35 (m, 5H), 7.33–7.30 (m, 2H), 7.23–7.18 (m, 2H), 5.53 (d, 1H, *J* 4.8 Hz), 5.52 (d, 1H, *J* 1.2 Hz), 5.42 (d, 1H, *J* 1.2 Hz), 5.36 (s, 1H), 5.33 (d, 1H, *J* 4.6 Hz), 5.13 (s, 1H), 4.50–4.47 (m, 1H), 4.38–4.36 (m, 1H), 4.13 (dd, 1H, *J* 4.6, 11.2 Hz), 3.86 (dd, 1H, *J* 3.0, 11.2 Hz), 3.73 (dd, 1H, *J* 3.1, 10.6 Hz), 3.69–3.65 (m, 2H), 3.44–3.39 (m, 1H), 3.38 (s, 3H), 1.30–1.29 (m, 2H), 1.23–1.16 (m, 10H), 0.80–0.77 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ_C, 166.21, 166.08, 165.85, 165.58, 133.84, 133.80, 133.75, 133.62, 130.35, 130.24, 129.84, 129.77, 129.59, 129.89, 128.86, 128.82, 128.71, 106.45, 106.01, 82.73, 82.21, 81.97, 78.12, 77.81, 72.55, 67.85, 66.69, 59.89, 32.25, 29.98, 29.84, 29.70, 26.60, 23.07, 14.50; ESIMS: *m*/*z* calcd for $[C_{47}H_{52}O_{13}]Na^+$: 847.3300. Found: 847.3230.

3.24. Octyl 5-azido-2,3-di-*O*-benzoyl-5-deoxy-α-D-arabinofuranosyl-(1 → 5)-2,3-di-*O*-benzoyl-α-D-arabinofuranoside (36)

Disaccharide **36** was prepared from **21**[43] (100 mg, 0.21 mmol), and **26** (113 mg, 0.23 mmol) and powdered molecular sieves (4 Å, 100 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (70 mg, 0.31 mmol) and silver triflate (10 mg, 0.04 mmol). Purification of the product by chromatography (6:1 hexanes–EtOAc) gave **36** (155 mg, 88%) as an oil: R_f 0.62 (4:1 hexanes–EtOAc); $[\alpha]_D$ +103.7° (*c* 0.7, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ_H, 8.02–8.01 (m, 2H), 7.97–7.95 (m, 4H), 7.86–7.84 (m, 2H), 7.54–7.50 (m, 2H), 7.49–7.44 (m, 1H), 7.43–7.31 (m, 7H), 7.22–7.18 (m, 2H), 5.57 (d, 1H, *J* 0.8 Hz), 5.52 (d, 1H, *J* 5.1 Hz), 5.43 (d, 1H, *J* 1.2 Hz), 5.38 (s, 1H), 5.28 (d, 1H, *J* 4.5 Hz), 5.14 (s, 1H), 4.51–4.49 (m, 1H), 4.37–4.34 (m, 1H), 4.12 (dd, 1H, *J* 4.6, 11.2 Hz), 3.88 (dd, 1H, *J* 2.9, 11.2 Hz), 3.73 (dd, 1H, *J* 2.9, 13.2 Hz), 3.68–3.63 (m, 1H), 3.54 (dd, 1H, *J* 4.8, 13.2 Hz), 3.44–3.39 (m, 1H), 1.53–1.50 (m, 2H), 1.21–1.16 (m, 10H), 0.80–0.77 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ_C, 166.33, 166.11, 165.85, 165.59, 133.98, 133.88, 133.80, 133.76, 130.31, 130.23, 129.75, 129.57, 129.36, 128.96, 128.84, 128.75, 106.26, 105.98, 83.27, 82.22, 82.21, 81.94, 78.83, 67.86, 66.64, 32.25, 29.97, 29.84, 29.70, 26.59, 23.07, 14.50; ESIMS: *m*/*z* calcd for $[C_{46}H_{49}N_3O_{12}]Na^+$: 858.3208. Found: 858.3279.

3.25. Octyl 2,3-di-*O*-benzoyl-5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 3)-2,5-di-*O*-benzoyl-α-D-arabinofuranoside (37)

Disaccharide **37** was prepared from **23**[43] (50 mg, 0.10 mmol), and **24** (60 mg, 0.13 mmol) and powdered molecular sieves (4 Å, 150 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (29 mg, 0.13 mmol) and silver triflate (11 mg, 0.04 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) to give **37** (75 mg, 92%) as an oil: R_f 0.43 (4:1 hexanes–EtOAc); $[\alpha]_D$ +121.6° (*c* 0.8, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 8.02–7.96 (m, 4H), 7.93–7.87 (m, 4H), 7.53–7.48 (m, 2H), 7.42–7.31 (m, 6H), 7.21–7.17 (m, 4H), 5.62 (s, 1H), 5.57 (s, 1H), 5.35 (d, 1H, *J* 4.2 Hz), 5.31 (s, 1H), 5.22 (s, 1H), 4.74–4.66 (m, 1H), 4.62–4.54 (m, 2H), 4.48–4.43 (m, 1H), 4.36–4.26 (m, 3H), 3.71–3.65 (m, 1H), 3.48–3.41 (m, 1H), 1.56–1.51 (m, 2H), 1.30–1.17 (m, 10H), 0.81–0.77 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 166.40, 165.97, 165.75, 165.36, 133.78, 133.73, 133.63, 133.30, 130.19, 130.13, 130.05, 129.87, 129.50, 129.31, 128.74, 128.69, 128.51, 106.09, 105.55, 83.47 (d, *J* 19.0 Hz), 83.11, 82.11 (d, *J* 172.7 Hz), 81.44, 81.39, 77.48, 77.05 (d, *J* 6.4 Hz), 67.94, 32.04, 39.65, 29.52, 29.44, 26.25, 22.84, 14.29; ESIMS: *m*/*z* calcd for $[C_{46}H_{49}FO_{12}]Na^+$: 835.3100. Found: 835.3092.

3.26. Octyl 2,3-di-*O*-benzoyl-5-*O*-methyl-α-D-arabinofuranosyl-(1 → 3)-2,5-di-*O*-benzoyl-α-D-arabinofuranoside (38)

Disaccharide **38** was prepared from **23**[43] (20 mg, 0.05 mmol), and **25** (55 mg, 0.11 mmol) and powdered molecular sieves (4 Å, 150 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (50 mg, 0.22 mmol) and silver triflate (10 mg, 0.04 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) gave **38** (40 mg, 97%) as an oil: R_f 0.31 (4:1 hexanes–EtOAc); $[\alpha]_D$ +78.9° (*c* 0.9, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ_H, 8.09–7.97 (m, 8H), 7.59–7.57 (m, 4H), 7.51–7.34 (m, 6H), 7.28–7.24 (m, 2H), 5.66 (s, 1H), 5.60 (d, 1H, *J* 1.3 Hz), 5.44 (dd, 1H, *J* 0.8, 4.5 Hz), 5.39 (d, 1H, *J* 0.8 Hz), 5.23 (s, 1H), 4.73 (dd, 1H, *J* 2.8, 12.1 Hz), 4.61–4.52 (m, 1H), 4.48 (s, 1H), 4.50–4.45 (m, 1H), 4.37–4.35 (m, 1H), 3.84–3.67 (m, 3H), 3.56–3.47 (m, 1H), 3.39 (s, 3H), 1.64–1.61 (m, 2H), 1.36–1.24 (m, 10H), 0.87–0.84 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 166.61, 166.09, 165.91, 165.57, 134.06, 133.28, 133.77, 133.51, 133.41, 130.39, 130.31, 130.24, 130.18, 130.14, 130.11, 129.76, 129.75, 129.67, 128.99, 128.87, 128.81, 128.75, 128.67, 106.32, 105.72,

83.41, 83.16, 81.78, 81.26, 81.20, 77.92, 72.27, 68.12, 63.79, 59.86, 32.24, 29.85, 29.72, 29.63, 26.45, 23.04, 14.49; ESIMS: m/z calcd for $[C_{47}H_{52}O_{13}]Na^+$: 847.3300. Found: 847.3281.

3.27. Octyl 5-azido-2,3-di-*O*-benzoyl-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-2,5-di-*O*-benzoyl-α-D-arabinofuranoside (39)

Disaccharide **39** was prepared from **23**[43] (50 mg, 0.11 mmol), and **26** (57 mg, 0.12 mmol) and powdered molecular sieves (4 Å, 150 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (34 mg, 0.15 mmol) and silver triflate (10 mg, 0.04 mmol). Purification of the product by chromatography (6:1 hexanes–EtOAc) gave **39** (70 mg, 84%) as an oil: R_f 0.45 (4:1 hexanes–EtOAc); $[\alpha]_D$ +112.5° (*c* 1.0, $CHCl_3$); ^1H NMR (250 MHz, $CDCl_3$): δ_H, 7.98–7.84 (m, 8H), 7.51–7.43 (m, 3H), 7.38–7.26 (m, 7H), 7.19–7.13 (m, 2H), 5.59 (s, 1H), 5.53 (d, 1H, *J* 1.1 Hz), 5.28 (s, 1H), 5.25 (d, 1H, *J* 4.3 Hz), 5.14 (s, 1H), 4.62–4.57 (m, 1H), 4.46–4.45 (m, 1H), 4.41–4.35 (m, 2H), 4.28–4.23 (m, 1H), 3.69–3.60 (m, 1H), 3.56 (d, 1H, *J* 3.1 Hz), 3.49–3.37 (m, 2H), 1.58–1.49 (m, 2H), 1.24–1.13 (m, 10H), 0.78–0.73 (m, 3H); ^{13}C NMR (63 MHz, $CDCl_3$): δ_C, 166.59, 166.19, 165.96, 165.58, 133.98, 133.83, 133.49, 130.35, 130.26, 130.08, 129.73, 129.50, 128.92, 128.73, 106.28, 105.69, 83.86, 83.03, 81.81, 81.50, 81.18, 78.62, 68.14, 63.76, 52.16, 32.24, 29.86, 29.72, 29.63, 26.45, 23.04, 14.49; ESIMS: m/z calcd for $[C_{46}H_{49}N_3O_{12}]Na^+$: 858.3208. Found: 858.3206.

3.28. Octyl 2,3-di-*O*-benzoyl-5-deoxy-5-fluoro-(1 → 3)-[2,3-di-*O*-benzozyl-5-deoxy-5-fluoro-α-D-arabinofuranosyl-(1 → 5)]-α-D-arabinofuranosyl-2-*O*-benzoyl-α-D-arabinofuranoside (40)

Trisaccharide **40** was prepared from **22**[43] (47 mg, 0.13 mmol) and [24] (140 mg, 0.30 mmol) and powdered molecular sieves (4 Å, 150 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (67 mg, 0.30 mmol) and silver triflate (21 mg, 0.08 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) to give **40** (110 mg, 81%) as an oil: R_f 0.33 (4:1 hexanes–EtOAc); $[\alpha]_D$ +101.5° (*c* 0.8, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 8.12–8.04 (m, 8H), 7.97–7.94 (m, 2H), 7.90–7.54 (m, 3H), 7.49–7.37 (m, 10H), 7.32–7.23 (m, 2H), 5.64 (s, 1H), 5.63 (d, 1H, *J* 4.8 Hz), 5.34 (s, 1H), 5.32 (d, 1H, *J* 4.2 Hz), 5.29 (d, 1H, *J* 1.2 Hz), 5.28–5.25 (m, 2H), 5.10 (s, 1H), 4.75 (d, 1H, *J* 3.2 Hz), 4.71–4.63 (m, 2H), 4.59–4.54 (m, 1H), 4.45–4.41 (m, 2H), 4.36–4.29 (m, 1H), 4.28–4.25 (m, 1H), 3.95 (dd, 1H, *J* 4.3, 11.4 Hz), 3.78 (dd, 1H, *J* 2.2, 11.4 Hz), 3.66–3.60 (m, 1H), 3.42–3.37 (m, 1H), 1.53–1.23 (m, 2H), 1.18–1.14 (m, 10H), 0.88–0.86 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 166.40, 165.95, 165.75, 165.32, 165.31, 133.78, 133.73, 133.63, 133.56, 133.52, 133.30, 130.19, 130.13, 130.05, 129.87, 129.50, 129.31, 129.13, 128.74, 128.69, 128.51, 106.27, 105.64, 105.53, 83.35, 83.05 (d, *J* 19.1 Hz), 82.79 (d, *J* 18.6 Hz), 82.17 (d, *J* 177.1 Hz), 82.01 (d, *J* 174.3 Hz), 81.67 (d, *J* 5.8 Hz), 81.20 (d, *J* 6.0 Hz), 77.48, 77.15, 67.87, 67.61, 66.41, 63.74, 33.05, 29.76, 29.67, 29.33, 26.14, 22.83, 14.27; ESIMS: m/z calcd for $[C_{56}H_{60}F_2O_{16}]Na^+$: 1073.3742. Found: 1073.3778.

3.29. Octyl 2,3-di-*O*-benzoyl-5-*O*-methyl-α-D-arabinofuranosyl-(1 → 3)-[2,3-di-*O*-benzoyl-5-*O*-methyl-α-D-arabinofuranosyl-(1 → 5)]-2-*O*-benzoyl-α-D-arabinofuranoside (41)

Trisaccharide **41** was prepared from **22**[43] (20 mg, 0.05 mmol) and **25** (58 mg, 0.12 mmol) and powdered molecular sieves (4 Å, 150 mg) in dry CH_2Cl_2 (10 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (60 mg, 0.26 mmol) and silver triflate (10 mg, 0.04 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) gave **41** (50 mg, 93%) as an oil: R_f 0.32 (4:1 hexanes–EtOAc); $[\alpha]_D$ +113.4° (*c* 1.4, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$): δ_H, 8.09–8.05 (m, 5H), 8.03–7.99 (m, 3H), 7.97–7.95 (m, 2H), 7.61–7.51 (m, 3H), 7.48–7.42 (m, 8H), 7.39–7.36 (m, 2H), 7.31–7.28 (m, 2H), 5.56–5.55 (m, 2H), 5.47 (s, 1H), 5.41–5.38 (m, 2H), 5.36 (s, 1H), 5.35 (s, 1H), 5.17 (s, 1H), 4.50–4.49 (m, 1H), 4.48–4.46 (m, 1H), 4.38–4.33 (m, 2H), 4.08 (dd, 1H, *J* 4.7, 11.4 Hz), 3.85 (dd, 1H, *J* 2.4, 11.4 Hz), 3.79 (dd, 1H, *J* 2.9, 10.5 Hz), 3.74–3.69 (m, 3H), 3.65 (dd, 1H, *J* 5.5, 10.5 Hz), 3.49–3.45 (m, 1H), 3.44 (s, 3H), 3.34 (s, 3H), 1.60–1.57 (m, 2H), 1.32–1.23 (m, 10H), 0.87–0.84 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ_C, 165.99, 165.89, 165.77, 165.29, 165.28, 133.63, 133.60, 133.48, 130.18, 130.11, 130.08, 130.01, 129.98, 129.51, 129.36, 128.67, 128.65, 128.59, 128.52, 106.10, 106.02, 105.42, 83.10, 82.91, 82.68, 81.65, 81.53, 81.52, 80.62, 77.95, 77.73, 72.37, 72.22, 67.73, 65.98, 59.69, 59.61, 32.04, 29.62, 29.56, 29.44, 26.24, 22.85, 14.31; ESIMS: m/z calcd for $[C_{60}H_{66}O_{18}]Na^+$: 1097.4141. Found: 1097.4124.

3.30. Octyl 2,3-di-*O*-acetyl-5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 3)-[2,3-di-*O*-acetyl-5-azido-5-deoxy-α-D-arabinofuranosyl-(1 → 5)]-2-*O*-benzoyl-α-D-arabinofuranoside (42)

Trisaccharide **42** was prepared from **22**[43] (48 mg, 0.13 mmol) and **26** (160 mg, 0.33 mmol) and powdered molecular sieves (4 Å, 200 mg) in dry CH_2Cl_2 (15 mL) as described for the synthesis of **34** using *N*-iodosuccinimide (75 mg, 0.33 mmol) and silver triflate (16 mg, 0.06 mmol). Purification of the product by chromatography (4:1 hexanes–EtOAc) gave **42** (97 mg, 68%) as an oil: R_f 0.54 (4:1 hexanes–EtOAc); $[\alpha]_D$ +101.4° (*c* 0.7,

$CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ_H, 8.10–8.03 (m, 8H), 7.95–7.93 (m, 2H), 7.91–7.51 (m, 3H), 7.49–7.37 (m, 10H), 7.30–7.25 (m, 2H), 5.60 (d, 1H, *J* 1.2 Hz), 5.59 (d, 1H, *J* 1.2 Hz), 5.49 (s, 1H), 5.42 (d, 1H, *J* 1.6 Hz), 5.39 (s, 1H), 5.32 (d, 1H, *J* 4.9 Hz), 5.30 (d, 1H, *J* 4.9 Hz) 5.19 (s, 1H), 4.49 (dd, 1H, *J* 1.0, 6.0 Hz), 4.45–4.42 (m, 1H), 4.37–4.32 (m, 2H), 4.06–4.02 (dd, 1H, *J* 4.5, 11.3 Hz), 3.88–3.85 (dd, 1H, *J* 2.5, 11.3 Hz), 3.79–3.68 (m, 3H), 3.61–3.54 (m, 2H), 3.48–3.46 (m, 1H), 1.58–1.57 (m, 2H), 1.26–1.23 (m, 10H), 0.88–0.84 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ_C, 165.97, 165.95, 165.77, 165.21, 133.78, 133.75, 130.07, 130.05, 130.01, 129.95, 129.91, 129.91, 129.21, 129.16, 129.15, 129.01, 128.72, 128.69, 128.66, 128.56, 105.98, 105.89, 105.59, 83.60, 83.33, 82.88, 81.47, 81.39, 81.37, 80.96, 78.56, 78.39, 67.73, 65.86, 52.04, 52.03, 31.99, 29.58, 29.49, 19.39, 26.19, 22.80, 14.27; ESIMS: *m*/*z* calcd for $[C_{58}H_{60}N_6O_{16}]Na^+$: 1119.3958. Found: 1119.3968.

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References

1. Pablos-Mendez, A.; Raviglione, M. C.; Laszlo, A.; Binkin, N.; Reider, H. L.; Bustreo, F.; Cohn, D. L.; Lambregts-van Weezenbeek, C. S. B.; Kim, S. J.; Chaulet, P.; Nunn, P. *N. Engl. J. Med.* **1998**, *338*, 1641–1649 (Erratum *N. Engl. J. Med.* **1998**, *339*, 139).
2. Blanchard, J. S. *Annu. Rev. Biochem.* **1996**, *65*, 215–239.
3. Young, D. B.; Duncan, K. *Annu. Rev. Microbiol.* **1995**, *49*, 641–673.
4. Havlir, D. V.; Barnes, P. F. *N. Engl. J. Med.* **1999**, *340*, 367–373.
5. Barnes, P. F.; Bloch, A. B.; Davidson, P. T.; Snider, D. E., Jr. *N. Engl. J. Med.* **1991**, *324*, 1644–1650.
6. Burman, W. J.; Jones, B. E. *Am. J. Resp. Crit. Care* **2001**, *164*, 7–12.
7. Schluger, N. W. *Clin. Infect. Dis.* **1999**, *28*, 130–135.
8. Barry, C. E., III; Slayden, R. A.; Sampson, A. E.; Lee, R. E. *Biochem. Pharmacol.* **2000**, *59*, 221–231.
9. Bass, J. B., Jr.; Farer, L. S.; Hopewell, P. C.; Obrien, R.; Jacobs, R. F.; Ruben, F.; Snider, D. E.; Thornton, G. *Am. J. Respir. Crit. Care Med.* **1994**, *149*, 1359–1374.
10. Lane, H. C.; La Montagne, J. R.; Fauci, A. S. *Nature Med.* **2001**, *7*, 1271–1273.
11. Lowary, T. L. Mycobacterial Cell Wall Components. In *Glycoscience: Chemistry and Chemical Biology*; Fraser-Reid, B., Tatsuta, K., Thiem, J., Eds.; Springer: Berlin, 2001; pp 2005–2080.
12. Brennan, P. J.; Nikaido, H. *Annu. Rev. Biochem.* **1995**, *64*, 29–63.
13. Barry, C. E., III. *Biochem. Pharmacol.* **1997**, *54*, 1165–1171.
14. Rastogi, N.; David, H. L. *Res. Microbiol.* **1993**, *144*, 133–143.
15. Besra, G. S.; Brennan, P. J. *J. Pharm. Pharmacol.* **1997**, *49* (Suppl. 1), 25–30.
16. Crick, D. C.; Mahapatra, S.; Brennan, P. J. *Glycobiology* **2001**, *11*, 107R–118R.
17. Ayers, J. D.; Lowary, T. L.; Morehouse, C. B.; Besra, G. S. *Bioorg. Med. Chem. Lett.* **1998**, *8*, 437–442.
18. Subramaniam, V.; Lowary, T. L. *Tetrahedron* **1999**, *55*, 5965–5976.
19. Yin, H.; D'Souza, F. W.; Lowary, T. L. *J. Org. Chem.* **2002**, *67*, 892–903.
20. McGurk, P.; Chang, G. X.; Lowary, T. L.; McNeil, M.; Field, R. A. *Tetrahedron Lett.* **2001**, *42*, 2231–2234.
21. Centrone, C.; Lowary, T. L. *J. Org. Chem.* **2002**, *67*, 8862–8870.
22. Centrone, C.; Lowary, T. L. *J. Org. Chem.* **2003**, *68*, 8115–8119.
23. Mikusová, K.; Slayden, R. A.; Besra, G. S.; Brennan, P. J. *Antimicrob. Agents Chemother.* **1995**, *39*, 2484–2489.
24. Deng, L.; Mikusová, K.; Robuck, K. G.; Scherman, M.; Brennan, P. J.; McNeil, M. R. *Antimicrob. Agents Chemother.* **1995**, *39*, 694–701.
25. Khoo, K.-H.; Douglas, E.; Azadi, P.; Inamine, J. M.; Besra, G. S.; Mikusová, K.; Brennan, P. J.; Chatterjee, D. *J. Biol. Chem.* **1996**, *271*, 28682–28690.
26. Lowary, T. L. *Mini-Rev. Med. Chem.* **2003**, *3*, 694–707.
27. Marotte, K.; Ayad, T.; Genisson, Y.; Besra, G. S.; Baltas, M.; Prandi, J. *Eur. J. Org. Chem.* **2003**, 2557–2565.
28. Lee, R. E.; Protopopova, M.; Crooks, E.; Slayden, R. A.; Terrot, M.; Barry, C. E., III. *J. Comb. Chem.* **2003**, *5*, 172–187.
29. Pathak, A. K.; Pathak, V.; Suling, W. J.; Gurcha, S. S.; Morehouse, C. B.; Besra, G. S.; Maddry, J. A.; Reynolds, R. C. *Bioorg. Med. Chem. Lett.* **2002**, *10*, 923–928.
30. Scherman, M. S.; Kalbe-Bournonville, L.; Bush, D.; Xin, Y.; Deng, L.; McNeil, M. *J. Biol. Chem.* **1996**, *271*, 29652–29658.
31. Scherman, M.; Weston, A.; Duncan, K.; Whittington, A.; Upton, R.; Deng, L.; Comber, R.; Friedrich, J. E.; McNeil, M. *J. Bacteriol.* **1995**, *177*, 7125–7130.
32. Lee, R. E.; Brennan, P. J.; Besra, G. S. *Glycobiology* **1997**, *7*, 1121–1128.
33. Singh, S.; Hogan, S. E. *Microbios* **1994**, *77*, 217–222.
34. Qian, X.; Palcic, M. M. *Carbohydr. Chem. Biol.* **2000**, *3*, 293–312.
35. Spohr, U.; Hindsgaul, O.; Lemieux, R. U. *Can. J. Chem.* **1985**, *63*, 2644–2648.
36. Mukherjee, A.; Palcic, M. M.; Hindsgaul, O. *Carbohydr. Res.* **2000**, *326*, 1–21.
37. Hindsgaul, O.; Kaur, K. J.; Srivastava, G.; Blaszczyk-Thurin, M.; Crawley, S.; Heerze, L. D.; Palcic, M. M. *J. Biol. Chem.* **1991**, *266*, 17858–17862.
38. Glaudemans, C. P. J.; Kovác, P.; Nashed, E. M. *Methods Enzymol.* **1994**, *247*, 305–322.
39. Bundle, D. R.; Eichler, E.; Gidney, M. A. J.; Meldal, M.; Ragauskas, A.; Sigurskjold, B. W.; Sinnott, B.; Watson, D. C.; Yaguchi, M.; Young, N. M. *Biochemistry* **1994**, *33*, 5172–5182.
40. Lemieux, R. U. *Acc. Chem. Res.* **1996**, *29*, 373–380.
41. Lowary, T. L.; Hindsgaul, O. *Carbohydr. Res.* **1994**, *251*, 33–67.
42. Laferté, S.; Chan, N. W. C.; Sujino, K.; Lowary, T. L.; Palcic, M. M. *Eur. J. Biochem.* **2000**, *267*, 4840–4849.
43. Cociorva, O. M.; Lowary, T. L. *Tetrahedron* **2003**, *60*, 1483–1491.
44. Pathak, A. K.; Pathak, V.; Maddry, J. A.; Suling, W. J.; Gurcha, S. S.; Besra, G. S.; Reynolds, R. C. *Bioorg. Med. Chem.* **2001**, *9*, 3145–3151.

45. D'Souza, F. W.; Ayers, J. D.; McCarren, P. R.; Lowary, T. L. *J. Am. Chem. Soc.* **2000**, *122*, 1251–1260.
46. Lambert, J. B.; Shurvell, H. F.; Lightner, D. A.; Cooks, R. G. *Organic Structural Spectroscopy*; Prentice-Hall: New York, 1998; p 193.
47. Mizutani, K.; Kasai, R.; Nakamura, M.; Tanaka, O.; Matsuura, H. *Carbohydr. Res.* **1989**, *185*, 27–38.
48. Pathak, A. K.; Pathak, V.; Kulshrestha, M.; Kinnaird, D.; Suling, W. J.; Gurcha, S. S.; Besra, G. S.; Reynolds, R. C. *Tetrahedron* **2003**, *59*, 10239–10248.