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A useful strategy for synthesis of the disaccharide of OSW-1⁺

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A flexible, efficient, and practical synthesis route was developed to synthesize an OSW-1 disaccharide. The synthesis took 13 steps from L-arabinose and D-xylose derivatives, and the overall yield was 7.2%. The region preferentially protects various D-xylose hydroxides because the TBS group selectively reacts with this hydroxide at low concentrations due to greater activity at the C-4 hydroxyl of D-xylose. Then, high efficiency selectively protects C-2 hydroxyl and C-3 hydroxyl of D-xylose, respectively. The first high yield of glycosylation on an OSW-1 synthesis disaccharide was achieved by taking sulfide donor 4 with β -PMP anomeric L-arabinose acceptor 12. The cytotoxicity reveals that the analogy has a high IC50 for a variety of cell types. This approach should provide a versatile way to modify OSW-1's disaccharide.

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Introduction

A natural saponin, OSW-1, was isolated from the bulbs of *Ornithogalum saudersiae* by Sashida *et al.* in 1992.¹ Pharmacological studies showed that OSW-1 exhibits exceptionally potent antitumor activities in nanomolar concentration (IC50 0.1–0.7 nM).^{2a} It is more potent than those used in clinical treatment as anticancer agents such as mictomycincadeiamycin and Taxol.² Therefore, the higher potential anticancer activity and structure of OSW-1 has always attracted chemists and biologists.³

The structure of OSW-1 can be separated into two parts: aglycon and disaccharide moieties. Fuchs et al. reported the first synthesis of the aglycone portion of OSW-1 in 1998.^{3a} Yu et al. reported the first complete synthesis of OSW-1 in 1999.3b Jin et al. published another complete synthesis of OSW-1 in 2001.3c Even though many synthetic methods for the preparation of disaccharides have been published to date,³⁻⁶ Yu's method appears to be the most straightforward and practical. However, they used hydrogenation to remove the benzyl group. Three major types of donors have been reported (Scheme 1), Jin's group reported 10 steps from D-xylose to generate the type I donor.^{3c,d} Yu's group reported the shortest synthesis from Dxylose to generate the type II donor, ^{3b,f,6e,13a} but they had to use hydrogenation to remove the benzyl group. Seven steps from Dxylose to generate type III donor by using 2,3-butanedione to selective protection of the 3,4-diol moiety of D-xylose,^{6b} but this

donor does not very commonly apply in total synthesis OSW-1 or analogies. Though these three types of donors use different protection groups, there is the same concept of using the same group to protect the 3,4-diol moiety of D-xylose. The structureactivity relationship studies of OSW-1 found that the disaccharide moiety, particularly the C-2 position of 4-methoxybenzoyl (MBz) and C-2' position of groups acetyl (Ac) at the disaccharide unit, play a critical role. Recently, a lot of studies on site-selective functionalization of carbohydrates have been reported.7 Sakurai group reported the synthesis of OSW-1 derivatives via site-selective acylation on the xylose moiety, and they discovered an effective approach was to insert fluorescence or a biotin moiety on the xylose portion with no activity loss.⁸ Therefore, developing a route to simplify the selective modification of xylose and provide a flexible intermediate compound for OSW-1 or analogies modification at the end of the synthesis is extremely important.

In this report, we describe a flexible, efficient, and practical synthesis of the disaccharide moiety, with a focus on shortening the xylose donor synthesis route and selectively introducing different groups at C-2 hydroxyl, C-3 hydroxyl and C-4 hydroxyl on the xylose donor. We specifically report the acceptable yield



Scheme 1 Synthetic plan for the disaccharide moiety.

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of glycosylation in this disaccharide utilizing a sulfide donor. Meanwhile, the presence of β -PMP in the anomeric position of arabinose caused C-3' hydroxyl to be more active than C-4' hydroxyl, which improved the yield of glycosylation (Scheme 1).

Result and discussion

The synthesis of the xylose moiety was outlined in Scheme 2 utilizing xylose as a starting material, and compound **1** was synthesized as described in the literature.^{3c,d}

The crucial step was regioselective introducing the TBS protect group to the C-4 hydroxy position. After optimization of the reaction conditions (Table S1[†]), we found that a low concentration of 1 was prepared initially in dry dichloromethane, followed by slowly adding TBSCl at room temperature to afford regioselective 2a in a yield of 85%. However, we noticed that when TBSOTf replaced TBSCl or increased the concentration of compound 1, the yield of 2a was decreased, and in the meantime, we acquired a by-product that was both C-4 and C-2 hydroxyl position protected. Encouraging by successfully synthesized compound 2a, we plan to introduce another different group at the 4-hydroxyl position of xylose, after scanning several conditions (Table 1). Compound 1 could regio-selectively react with ally chloroformate using N,N-diisopropylethylamine (DIPEA) as a base to afford 2b in 70%. Meanwhile, treating compound 1 with levulinic acid and N,N'-



Scheme 2 Reaction condition: (a) TBSCl (1.1 eq.), imidazole, DCM (c = 0.02), rt, 85% yield; (b) MBzCl, DMAP, Et₃N, DCM, room temperature, 2 h, 81% yield; (c) TESOTf, DMAP, Et₃N, DMF, room temperature, 2 h, 79% yield; (d) NBS, acetone/aq. NaHCO₃ (5 : 1), 30 min, rt, 86% yield; (e) Cl₃CCN, DBU, DCM, overnight, room temperature, 87% yield.

diisopropylcarbodiimide to afford compound **2c**, even though the yield was moderate (57%). This result successfully supplied an extra protection group in the xylose moiety.

With compound 2a in hand, we have tried to finish the rest of the xylose part. The C-2 hydroxyl site was selectively acetylated using *p*-methoxybeznoyl chloride to yield 3 (Scheme 2). While compound 2a is reacted with ally chloroformate using triethylamine (Et₃N) as a base, it produced the high-yield product 3a, which provides more options for disaccharide modification, as shown in ref. 9. The TES protection of the C-3 hydroxy position by TESOTf in dimethylformamide (DMF) went off without a hitch. We tried a variety of different conditions (Table S2[†]), such as using a different solvent (e.g., dichloromethane or tetrahydrofuran) or replacing TESOTf with TESCl as the reagent, but only the reaction employing TESOTf in DMF with DMAP yielded the best results. Finally, hemiacetal 5 was obtained by deprotecting S-Tol of glycoside 4 in the presence of N-bromosuccinimide, followed by trichloroacetimidation with trichloroacetonitrile under normal conditions to generate. After five steps from compound 1, the target Schmidt donor 6 was produced with a total yield of 39%.

The acceptor synthesis is depicted in Scheme 3. β-PMPglycoside 8 was made from tetra-acetyl-1-arabinose 7 utilizing BF₃Et₂O as a promoter, and the acetyl group was deprotected with sodium methoxide to afford 9. Protection of the cis-3',4'diol 9 with 2,2-dimethoxypropane resulted in 10, while protection of the C-2' hydroxy group with acetyl anhydride resulted in **11.** The 3',4'-acetonide was deprotected by 70% acetic acid/H₂O, yielding diol 12. We attempted to protect position C-4'hydroxy with TESCl reagent, but C-3' hydroxyl protected as the major product, and only 19% of the desired compound 13. This result is different from the α -anomeric position which only protected C-4' hydroxyl with TESCl reagent.3c,d The C-4' hydroxyl selectivity has been observed in the previous attempts to synthesize OSW-1 analogues,6 including a detailed analysis by Pakulski and coworkers. They concluded this unusual C-4' hydroxyl selectivity to a novel equatorial C-4' hydroxyl of arabinose with the ¹C₄ conformation constrained by the intramolecular hydrogen bonding between C-3' hydroxyl and the cis-anomeric oxygen atom of arabinoside. We assume that the presence of β -PMP in the anomeric position causes C-3' hydroxyl more active than C-4'

Table 1	Regioselectivity	introducing the	protecting	group to	the C-4	OH position
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1 HO DH L Me							
Entry	Condition	Result					
1	TBSCI (1.1 eq.), imidazole DCM ($c = 0.02$), rt	TBSO VIL					
2	Allyl chloroformate (1.1 eq.), DIPEA ($c = 0.02$), 0 °C	HO Zb OH S Me					
3	Levulinic acid (1.1 eq.), DIC, Et_3N DCM ($c = 0.02$), rt	Me Contraction State Sta					

HOUS S Condition BO S



Scheme 3 Reaction condition: (a) PMP-OH, $BF_3 \cdot Et_2O$, DCM, 0–25 °C. 3 days, 57% yield; (b) MeONa, MeOH, 95% yield; (c) CAS, 2,2-dimethoxypropane, DMF, 50 °C, 90% yield; (d) Ac₂O, pyridine, 94% yield; (e) 70% AcOH, 86% yield; (f) TESCI, Et₃N, DCM, -50 °C, 25% yield.

hydroxyl, which is consistent with Pakulski's report.^{6c,d} The structure of compound **13** was confirmed by 2D NMR after being treated with chloroacetyl chloride (as shown in ESI†). With compounds **6** and **13** in hand, we focused on glycosylation. After optimization of the reaction conditions (Table S3†), we found that the glycosylation of **13** with **6** as glycosyl donor and 0.1 eq. BF₃·Et₂O as a promoter, the reaction gave **15** with a yield of 78%. This result confirmed that glycosylation occurred in the presence of BF₃·Et₂O, but the yield of compound **13** is insufficient. Meanwhile, we realized that utilizing **12** as the acceptor directly should be the better option. After five processes, the necessary acceptor **12** was prepared with a total yield of 40%.

In the presence of $BF_3 \cdot Et_2O$, glycosylation of **12** with **6** as the glycosyl donor resulted in an inseparable mixture of disaccharides **13** and **14** (Scheme 4). The protection of the mixture compound with TESCl using Et_3N as the base. The disaccharide **15** (72% yield) and **16** (20% yield) were obtained by chromatographic separation of the combination using DCM with hexane as elution.

Even though we were able to properly produce disaccharide **15**, this synthesis method is not very efficient. In 2008, Guo *et al.*, attempted to glycosylate this disaccharide by a sulfide



Scheme 4 Reaction condition: (a) $BF_3 \cdot Et_2O$ (0.1 eq.), 4 Å MS, DCM, -60 °C, 1.5 h; (b) TESOTF, Et_3N , room temperature, DCM, 2 h.

donor with α -acetyl anomeric acceptor, but were unsuccessful, despite employing *N*-iodosuccinimide (NIS) and triflic acid as promoters or bromine as a promoter with silver triflate.¹⁰ In 2019, Yu's group achieved the glycosylation of this disaccharide by a sulfide donor with a β -benzyl anomeric acceptor, but only 23% yield of the desired product. We thus decided to undertake the direct glycosylation of sulfide donor and β -PMP anomeric acceptor in one-pot reaction. After optimization of the glycosylation of this disaccharide by a sulfide donor with β -PMP anomeric acceptor (Table S4†), we found that utilizing NIS and BF₃·Et₂O as promoters, the glycosylation of **12** with **4** was successfully generated a mixture of the target **13** and by-product





	IC ₅₀ (nM)								
	HCT-50	HeLa	MDA-MB-231	MCF-7	SKOV-3	HMC-3M	MCF-10A		
WB-06	95.6	18.6	20.5	16.3	22.1	65.1	56.3		
Taxol	57.8	2.1	5.5	12.1	9.8	_	_		

14, then TES protection to generate 15 in 68% (Scheme 5). Furthermore, we confirmed β -PMP anomeric enhanced 3'-hydroxyl activity by using compound 13 as an accepter to glycosylate with donor 4 using NIS and BF₃Et₂O as promoters generated compound 15 in a 65% yield, as shown in ref. 11. Finally, hemiacetal 17 was obtained by deprotecting PMP of glycoside 15 in the presence of CAN, followed by trichloroacetimidation with trichloroacetonitrile under normal conditions to generate 18.

Sapogenin 20 was synthesized from diosgenin using a process described in the literature (Scheme 6).¹² The OSW-1 analogy was synthesized with both aglycon 20 and the disaccharide donor 18 readily hand. Under typical conditions, compound 20 reacted with disaccharide donor 18 to produce 21. The OSW-1 analogue WB-6 was produced by the deprotection of 21 with Pd (MeCN)Cl₂. The physical characteristics of WB-6 are the same as those reported.^{12b}

Antitumor activities in vitro

The synthetic OSW-1 analogue WB-06 was screened against HCT-8, HeLa, MDA-MB-231, MCF7, Skov-3. HMC-3, MCF-10A cell lines by alamarBlue cytotoxicity assay. Taxol was used as a positive control; all the experiments were repeated three times. The HCT-8, HeLa, MDA-MB-231, and MCF7 cell line was selected for comparison with the literature-reported OSW-1 or OSW-1 analogy cytotoxicity data.12c,13 All of the other cell lines were screened for the first time. The results presented in Table 2 illustrate the concentrations required for 50% cell death (IC50 values) when compared to the vehicle-treated negative control. The IC50 value for WB-6 range from 18.6 nM to 110.6 nM less active to Taxol. In particular, the IC50 value for HeLa, MDA-MB-231, and MCF7 cells is comparable to the literature-reported value. WB-6 also showed valuable benefits to Skov-3 cell lines. Unfortunately, no selectivity between tumor and non-tumor cell lines (HMC-3 and MCF-10A) was observed for WB-6.

The *in vitro* cytotoxicity against HCT-8 (colon carcinoma cell line), HeLa (cervical cancer cell line), MDA-MB-231 (Human Breast cancer cell line), MCF7 (breast cancer cell line), Skov-3 (ovarian cancer cell line), HMC-3 (human microglia cell line), MCF-10A (non-tumorigenic epithelial cell line) cell lines were evaluated by the standard MTT assay.

Conclusions

Finally, we have developed a flexible synthesis strategy for OSW-1 disaccharide, which was synthesized in 13 steps with an overall yield of 7.2% from xylose derivate **1** and arabinose derivate 7. A new and effective process for preparing disaccharide building blocks has been created. Donor 4 was achieved by protecting the C-2, C-3, and C-4 hydroxyl positions independently, allowing for easy modification. The xylose donor moiety is useful for studying the structure–activity relationship of OSW-1 and discovering new anticancer treatments. Specifically, the first high yield of glycosylation on an OSW-1 synthesis disaccharide was achieved by sulfide donor 4 with β -PMP anomeric Larabinose acceptor 12. The cell analysis shows that analogy has higher anti-tumor potential. This strategy should provide a versatile way to modify OSW-1's disaccharide. Further application of this disaccharide to generate OSW-1 and analogies is in progress in our laboratory.

Conflicts of interest

The authors declare no competing financial interest.

Acknowledgements

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- 9 While compound 3a is reacted with ally chloroformate using triethylamine (Et₃N) as a base, it produces the high yield product 4a, which provides more options for disaccharide modification.

$$\underset{HO}{\mathsf{TESO}} \underbrace{\overset{\circ}{\underset{DH}}}_{2a} \overset{\circ}{\underset{HO}} \underbrace{\overset{\circ}{\underset{DH}}}_{Me} \overset{\circ}{\underset{HO}} \underbrace{\overset{\circ}{\underset{D}}}_{HO} \underbrace{\overset{\circ}{\underset{D}}}_{0} \overset{\circ}{\underset{D}} \overset{\circ}{\underset{D}} \underbrace{\overset{\circ}{\underset{D}}}_{Me} \underbrace{\overset{\circ}{\underset{TESO}}} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{0} \overset{\circ}{\underset{D}} \overset{\circ}{\underset{D}} \underbrace{\overset{\circ}{\underset{D}}}_{He} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{0} \overset{\circ}{\underset{D}} \underbrace{\overset{\circ}{\underset{D}}}_{He} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{0} \overset{\circ}{\underset{D}} \overset{\circ}{\underset{D}} \underbrace{\overset{\circ}{\underset{D}}}_{He} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{0} \overset{\circ}{\underset{D}} \underbrace{\overset{\circ}{\underset{D}}}_{He} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{D} \underbrace{\overset{\circ}{\underset{D}}}_{He} \underbrace{\overset{\circ}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{D} \underbrace{\overset{\leftarrow}{\underset{D}}}_{TESO} \underbrace{\overset{\circ}{\underset{D}}}_{D} \underbrace{\overset{\circ}{\underset{D}}}_{D} \underbrace{\overset{\bullet}{\underset{D}}}_{TESO} \underbrace{\overset{\bullet}{\underset{D}}}_{D} \underbrace{\overset{\leftarrow}{\underset{D}}}_{D} \underbrace{\overset{\bullet}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}\\{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}\\{D} \underbrace{\overset}{\underset{D}}_{D} \underbrace{\overset}{\underset{D}}\\{D} \underbrace{\overset}$$

Scheme 7. Reaction condition: (a) allyl chloroformate, Et₃N,

DMF, room temperature, 2 h. (b) TESOTf, DMAP, Et_3N , DMF, room temperature, 2 h.

- 10 J. Xue, P. Liu, Y. B. Pan and Z. W. Guo, *J. Org. Chem.*, 2008, **73**, 157–161.
- 11 Compound 13 as an accepter to glycosylate with donor 4 using *N*-iodosuccinimide (NIS) and BF₃Et₂O as promoters generated compound 15.



Scheme 5. Reaction condition: (a) $BF_3 \cdot Et_2O$ (0.05 eq.), 4 Å MS, DCM, $-40~^{\circ}C.$

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