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## *ortho*-(Methyltosylaminoethynyl)benzyl glycosides as new glycosyl donors for latent-active glycosylation†

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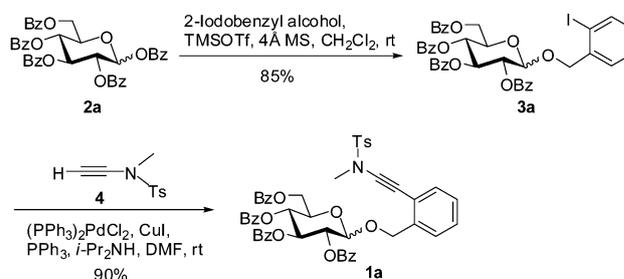
A new glycosylation protocol employing *ortho*-(methyltosylaminoethynyl)benzyl glycosides as glycosyl donors and TMSOTf as the catalyst is disclosed. These donors can be readily prepared from the corresponding 'latent' *ortho*-iodobenzyl glycosides *via* a Sonogashira coupling, thus providing a new approach for the 'latent-active' synthesis of glycans.

New glycosylation methods are continuously developed with efforts to construct the extremely diverse glycosidic linkages occurring in glycans and glycoconjugates in an efficient and economical manner.<sup>1</sup> In the last decade, much interest has been devoted to the investigation of glycosylation protocols based on activation of the C≡C triple bonds. Thus, propargyl glycosides and 1,2-orthoesters (under the catalysis of AuX<sub>3</sub>),<sup>2,3</sup> glycosyl alkynoates (under the promotion of Hg(OTf)<sub>2</sub>),<sup>4</sup> diproparglycyanoacetates (under the catalysis of AuCl<sub>3</sub>/AgSbF<sub>6</sub>),<sup>5</sup> as well as alkynyl-containing thioglycosides (under the catalysis of Au(I) complexes),<sup>6</sup> are disclosed to be effective donors in certain glycosylation reactions. Especially, glycosyl *ortho*-alkynylbenzoates (under the catalysis of a gold(I) complex, such as PPh<sub>3</sub>AuNTf<sub>2</sub> and PPh<sub>3</sub>AuOTf) have been found to have wide applications in the synthesis of complex glycans and glycoconjugates,<sup>7,8</sup> and the general mechanism of this glycosylation reaction has been largely elucidated.<sup>7c-e</sup> During the course of these studies, we tried glycosyl *ortho*-alkynylbenzyl glycosides as donors, which would have the advantage of easy manipulation of the protecting groups, but found no glycosylation took place under similar conditions wherein the corresponding *ortho*-alkynylbenzoates underwent glycosylation. We envisioned introduction of an electron-rich substituent on the alkyne moiety to facilitate the desired glycosylation pathway. Here we report *ortho*-(methyltosylaminoethynyl)benzyl glycosides

as a new type of glycosyl donors which can be activated by a catalytic amount of TMSOTf under mild conditions and their applicability in the 'latent-active' synthesis of glycans.

The desired glycosyl *ortho*-(methyltosylaminoethynyl)benzyl glycosides could be easily prepared from the corresponding *ortho*-iodobenzyl glycosides *via* a Sonogashira coupling with ynamide **4**.<sup>9-11</sup> Taking the preparation of perbenzoyl glucopyranoside **1a** as an example (Scheme 1), *ortho*-iodobenzyl glucopyranoside **3a** was obtained *via* condensation of perbenzoylated glucose **2a** with 2-iodobenzyl alcohol under the action of TMSOTf, which was then subjected to coupling with ynamide **4** in the presence of (PPh<sub>3</sub>)<sub>2</sub>PdCl<sub>2</sub> and CuI in *i*-Pr<sub>2</sub>NH/DMF to provide the desired *ortho*-(methyltosylaminoethynyl)benzyl glycoside **1a** in high yield (90%).<sup>10</sup> Manipulation of the protecting groups on the iodobenzyl glycoside **3a** followed by Sonogashira coupling would lead to (methyltosylaminoethynyl)benzyl glucopyranosides bearing different protecting group patterns, such as **1c** (Table 2). (Methyltosylaminoethynyl)benzyl rhamnopyranoside **1b** and 2-deoxy-glucopyranoside **1d** were similarly prepared by Sonogashira coupling as the key step (see ESI† for details). All these glycosides were found to be stable when stored at room temperature.

With the perbenzoyl glucoside **1a** as a potential donor and cholesterol **5a** as an acceptor, a variety of  $\pi$ -acids and Lewis acids (0.1 eq.) were screened as promoters for the desired



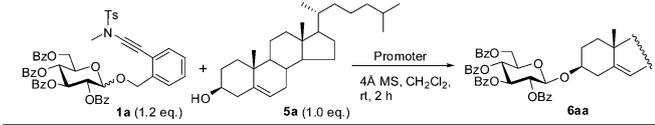
Scheme 1 Preparation of *ortho*-(methyltosylaminoethynyl)benzyl glucopyranoside **1a**.

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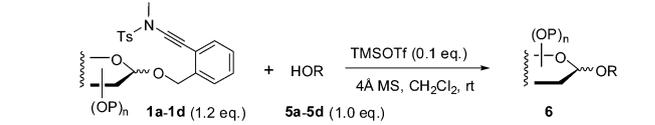
**Table 1** Screening of promoters for the glycosylation of *ortho*-(methyltosylaminoethynyl)benzyl glucoside **1a** with cholesterol **5a**


Entry	Promoter (0.1 eq.)	Isolated yield (%)
1	PPh <sub>3</sub> AuNTf <sub>2</sub>	43
2	TMSOTf	91
3	Bi(OTf) <sub>3</sub>	83
4	In(OTf) <sub>3</sub>	67
5	Cu(OTf) <sub>2</sub>	46
6	Sc(OTf) <sub>3</sub>	17
7	BF <sub>3</sub> OEt <sub>2</sub> (1.2 eq.)	21
8	SnCl <sub>4</sub>	26
9	PtCl <sub>2</sub>	16
10	AuBr <sub>3</sub>	Trace
11	CuI or LiOTf	No reaction

glycosylation reaction in the presence of 4 Å MS in CH<sub>2</sub>Cl<sub>2</sub> at room temperature (Table 1). Surprisingly, PPh<sub>3</sub>AuNTf<sub>2</sub>, the effective catalyst for the glycosylation of glycosyl *ortho*-alkynylbenzoates,<sup>7</sup> could not catalyze the present coupling effectively, providing the desired β-glucoside **6aa** in only 43% yield (entry 1). The major by-product arose from the nucleophilic addition of cholesterol **5a** onto the ynamide moiety.<sup>11a,e</sup> TMSOTf turned out to be the most effective catalyst, wherein the coupled glycoside **6aa** was obtained in a high yield of 91% (entry 2). Bi(OTf)<sub>3</sub>, In(OTf)<sub>3</sub>, and Cu(OTf)<sub>2</sub> were shown to be better catalysts than PPh<sub>3</sub>AuNTf<sub>2</sub>, leading to **6aa** in 83%, 67%, and 46% yield, respectively (entries 3–5). Sc(OTf)<sub>3</sub>, BF<sub>3</sub>OEt<sub>2</sub>, SnCl<sub>4</sub>, and PtCl<sub>2</sub> were found to be ineffective for this coupling (16–26%) (entries 6–9), whereas the coupling partners stayed inert in the presence of AuBr<sub>3</sub>, CuI, and LiOTf (entries 10 and 11).

Next, we investigated briefly the scope of the TMSOTf-catalyzed glycosylation reaction with *ortho*-(methyltosylaminoethynyl)benzyl glycosides as donors (Table 2). Four representative glycosides **1a–1d** and four alcohols **5a–5d** were selected as coupling partners, and all the reactions were carried out under fixed conditions (0.1 eq. TMSOTf, 4 Å MS, CH<sub>2</sub>Cl<sub>2</sub>, rt, 2 h). The couplings of perbenzoyl-glucopyranoside **1a** with all the four alcohols led to the coupled glycosides in excellent yields (>91%) and with complete β-selectivity (entries 1–4), testifying the participation of the neighbouring group in the glycosylation.<sup>1</sup> Similarly, the couplings of 2,3,4-tri-*O*-benzoyl-*L*-rhamnopyranoside **1b** with alcohols **5a–5d** provided the corresponding α-*L*-rhamnosides in a fully stereocontrolled manner in high yields (88–95%; entries 5–8). As expected, the corresponding glycosylation reactions of perbenzoyl-glucopyranoside **1c** and 2-deoxy-glucopyranoside **1d**, in the absence of a neighboring participating group, led to the coupled glycosides in high yields (83–99%), albeit in a pair of the α- and β-anomers (Table 2, entries 11–16).<sup>12,13</sup> It was noted that the reactions with the hindered glucose-4-OH derivative **5c** as the acceptor were devoid of the addition of alcohol onto the ynamide moiety, therefore the unglycosylated **5c** could be fully recovered.

In fact, the addition of alcohol onto the ynamide moiety became a serious problem when the alcohol to be glycosylated

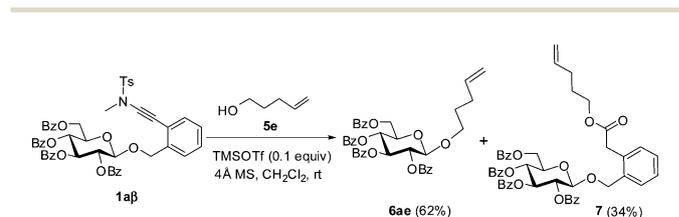
**Table 2** Glycosylation with *ortho*-(methyltosylaminoethynyl)benzyl glycosides **1a–1d** as donors under the catalysis of TMSOTf


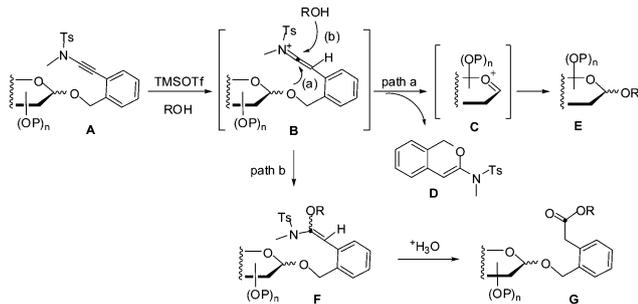
Entry	Donor	Acceptor	Product	Yield <sup>a</sup> [%]	α/β <sup>b</sup>
1	<b>1a</b>	<b>5a</b>	<b>6aa</b>	91	β only
2	<b>1a</b>	<b>5b</b>	<b>6ab</b>	91	β only
3	<b>1a</b>	<b>5c</b>	<b>6ac</b>	98	β only
4	<b>1a</b>	<b>5d</b>	<b>6ad</b>	94	β only
5	<b>1b</b>	<b>5a</b>	<b>6ba</b>	90	α only
6	<b>1b</b>	<b>5b</b>	<b>6bb</b>	95	α only
7	<b>1b</b>	<b>5c</b>	<b>6bc</b>	88	α only
8	<b>1b</b>	<b>5d</b>	<b>6bd</b>	91	α only
9	<b>1c</b>	<b>5a</b>	<b>6ca</b>	95	1:1
10	<b>1c</b>	<b>5b</b>	<b>6cb</b>	93	1.5:1
11	<b>1c</b>	<b>5c</b>	<b>6cc</b>	85	1.2:1
12	<b>1c</b>	<b>5d</b>	<b>6cd</b>	89	1.2:1
13	<b>1d</b>	<b>5a</b>	<b>6da</b>	93	1.8:1
14	<b>1d</b>	<b>5b</b>	<b>6db</b>	99	2.5:1
15	<b>1d</b>	<b>5c</b>	<b>6dc</b>	83	10:1
16	<b>1d</b>	<b>5d</b>	<b>6dd</b>	89	3:1

<sup>a</sup> Isolated yield. <sup>b</sup> The α/β ratio was determined by <sup>1</sup>H NMR spectroscopic measurement.

is highly reactive. Thus, the condensation of **1a** with 4-penten-1-ol **5e** under the catalysis of TMSOTf delivered the coupled glycoside **6ae** in only 62% yield, while ester **7**, which was derived from the corresponding adduct during workup, was isolated in 34% yield (Scheme 2).<sup>11</sup>

Based on these experimental findings and the nature of ynamides,<sup>9,11</sup> a plausible mechanism for the present TMSOTf-catalyzed glycosylation reaction with *ortho*-(methyltosylaminoethynyl)benzyl glycosides as donors was proposed (Scheme 3). Thus, keteniminium cation **B** was generated from *ortho*-(methyltosylaminoethynyl)benzyl glycoside **A** in the presence of ROH and TMSOTf (wherein HOTf<sup>14</sup> was produced *in situ*).<sup>15</sup> An intramolecular nucleophilic addition of the anomeric oxygen onto

**Scheme 2** The coupling of *ortho*-(methyltosylaminoethynyl)benzyl glucopyranoside **1a** with 4-penten-1-ol (**5e**).

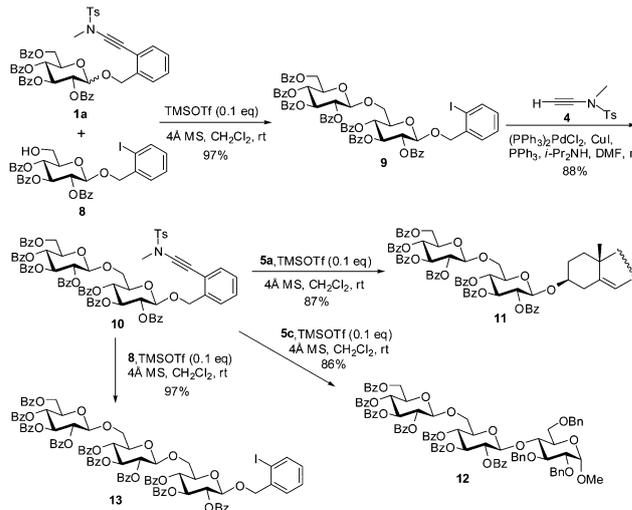


**Scheme 3** A plausible mechanism for the glycosylation with *ortho*-(methyltosylaminoethyl)benzyl glycosides as donors under the catalysis of TMSOTf.

the keteniminium led to sugar oxocarbenium ion **C** and 1*H*-isochromene **D** which was indeed characterized (path a). Sugar oxocarbenium ion **C** underwent glycosylation in the presence of ROH to provide glycoside **E**.<sup>1e</sup> Alternatively, keteniminium cation **B** could be attacked by the alcohol ROH, giving rise to alkoxy-substituted enamine intermediate **F** (path b). Hydrolysis of the enamine **F** during workup provided ester **G**.

Given the fact that the *ortho*-(methyltosylaminoethyl)-benzyl glycoside donors are readily prepared from the *ortho*-iodobenzyl glycosides, which are inactive in the glycosylation reactions of the former, these donors could be applied to the expeditious synthesis of oligosaccharides based on the 'latent-active' strategy.<sup>16</sup> The previous donors applicable in the 'latent-active' synthesis of glycans include *p*-acetamidophenyl thioglycosides (vs. *p*-nitrophenyl thioglycosides),<sup>17</sup> *n*-pentenyl glycosides (vs. 4,5-dibromopentyl glycosides),<sup>18</sup> vinyl glycoside (vs. 1-methyl-2-propenyl glycosides),<sup>19</sup> 2-(hydroxycarbonyl)benzyl glycosides (vs. 2-(benzyloxycarbonyl)benzyl glycosides),<sup>20</sup> and *S*-benzimidazolyl glycosides (vs. *N*-anisoylated *S*-benzimidazolyl glycosides).<sup>21</sup> To demonstrate the feasibility of applying the present glycosylation protocol to the 'latent-active' assembly of glycans, the 'active' *ortho*-(methyltosylaminoethyl)-benzyl glycoside **1a** was coupled with the 'latent' *ortho*-iodobenzyl glycoside derivative **8** in the presence of TMSOTf (0.1 eq.) to provide β-(1 → 6)-disaccharide **9** (97%), which was then converted into the 'active' *ortho*-(methyltosylaminoethyl)benzyl disaccharide **10** via Sonogashira coupling with ynamide **4** (88%) (Scheme 4). Subsequent glycosylation of disaccharide **10** with cholesterol **5a** or glucose-4-OH derivative **5c** under similar glycosylation conditions furnished cholesterol 3-*O*-β-disaccharide **11** and β-trisaccharide **12** in 87% and 86% yields, respectively. In addition, glycosylation of disaccharide **10** with the 'latent' *ortho*-iodobenzyl glycoside acceptor **8** provided the 'latent' *ortho*-iodobenzyl trisaccharide **13** in 97% yield, which could be used for further elongation of the glycans via the iterative Sonogashira coupling/glycosylation sequence.

In conclusion, *ortho*-(methyltosylaminoethyl)benzyl glycosides have been disclosed as a new type of glycosyl donors under the catalysis of TMSOTf. These shelf-stable donors are readily prepared from the corresponding *ortho*-iodobenzyl glycosides via Sonogashira coupling with ynamide **4**. The expeditious assembly of glycans via the 'latent-active' strategy using the present protocol has been demonstrated. These



**Scheme 4** Assembly of oligosaccharides **11–13** by the 'latent-active' strategy using *ortho*-(methyltosylaminoethyl)benzyl glycosides as donors and *ortho*-iodobenzyl glycosides as acceptors.

promising preliminary results shall warrant further elaboration and application of this new glycosylation method.

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