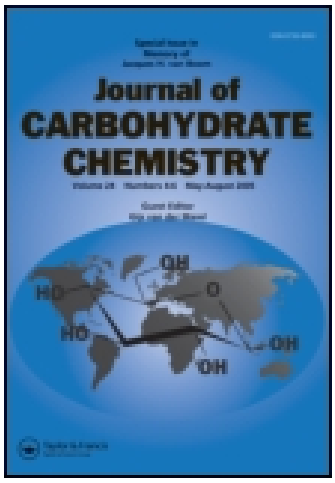

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Synthesis of *C*-3 Branched Allyl and Pentadienyl Glucosamines via Radical Coupling of Sugar-Thionocarbonates

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ABSTRACT

The intermolecular AIBN-promoted free radical reaction of glucosamine thionocarbonates as radical donors, and allyl or pentadienyl-tributyltin reagents gave the expected *C*-3 branched sugar derivatives in good yield and with total equatorial selectivity.

Key Words: *C*-Branched alkenyl sugars; Radical reaction; Pentadienyltributyltin; Allyltributyltin; Thionocarbonates.

INTRODUCTION

C-Branched alkenyl sugars are useful precursors for the synthesis of more complex *C*-glycosides.[1–6] For instance, benzyl 2-acetamido-3-*C*-allyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside **2** has been used for the synthesis of *C*-trisaccharides related to the H-type I blood group determinant.[7,8] More recently, Liu and Postema reported the preparation and use of various *C*-allyl branched sugars as starting materials

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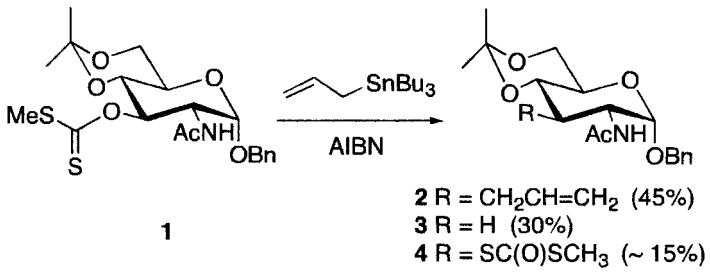
for the synthesis of *C*-disaccharides via metathesis.[9,10] Alternatively, we have shown that *C*-dienyl glycosides are useful precursors for the synthesis of *C*-disaccharide analogs by hetero Diels–Alder reaction.[11] These de novo strategies are highly attractive since they should allow stereostructural variation leading to molecular diversity. Since important naturally occurring oligosaccharides feature a *N*-acetyl glucosamine (GlcNAc) moiety substituted at the 3 position by a galactose (Gal) unit (H-type blood determinant or Lewis A) or a fucose (Fuc) residue (Lewis X), we have investigated the synthesis of *C*-allyl and penta-2′,4′-dienyl glucosamines via radical coupling using tributyltin derivatives.

RESULTS AND DISCUSSION

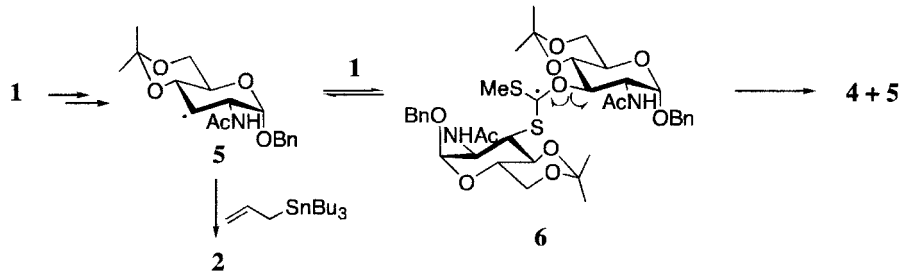
Preparation of the 3-*C*-allyl derivative **2** in 46% yield was reported by Sutherlin and Armstrong,[7,8] by an AIBN-initiated radical reaction of methyl dithiocarbonate (xanthate) **1** and allyltributyltin. However in our hands, isolation of pure **2** was rather troublesome. The radical coupling was therefore reinvestigated in order to improve both the yield of the reaction and the purification step. Paying careful attention to the known protocol,[7,8] we were able to isolate the pure target **2** (45%) as well as the 3-deoxysaccharide **3**[12] (30%) and the rearranged derivative **4** (∼15%) (Sch. 1). Despite the fact that the latter compound was slightly contaminated by **2**, its structure was established by NMR analysis and mass spectrometry. The mass spectrum indicated the same molecular peak as that of starting xanthate **1** but a signal at 169.7 ppm in the ^{13}C NMR spectra indicated the presence of a carbonyl group, whereas the thiocarbonyl group in compound **1** had a chemical shift of 217.6 ppm. Furthermore, because of the C–S linkage, the signal of C-3 in **4** was shielded by more than 30 ppm ($\delta = 46.6$ ppm) in respect to that of C-3 in xanthate **1** ($\delta = 78.8$ ppm).

Although **4** was a minor product relative to **2** and **3**, it was important to limit its formation since when present, the rearrangement product interfered with the monitoring of the reaction. Besides, it was difficult to separate the latter from allylic derivative **2**.

The Schönberg rearrangement[13–15] leading to **4**, i.e., the thermal *O* to *S* transposition of the dithiocarbonate, has been observed when xanthates were subjected to the Barton–McCombie reaction.[16–18] It arose, as explained by Quiclet-Sire and Zard,[16] when a sugar radical **5** adds to the thiocarbonyl group of another molecule of starting dithiocarbonate **1**, instead of reacting with allyltributyltin (Sch. 2).



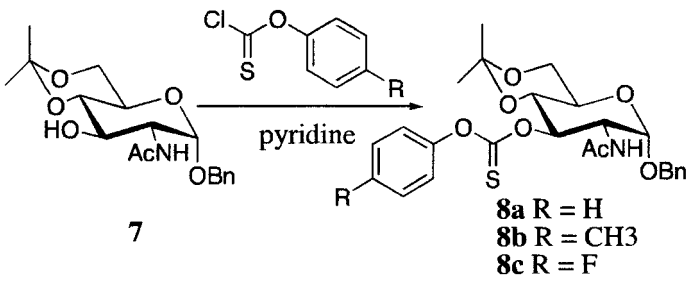
Scheme 1. AIBN-mediated radical coupling of xanthate **1** with allyl-tributyltin.



Scheme 2. Mechanism of the radical reaction involving **1**.

The heterolytic cleavage of intermediate **6** gives thiocarbonate **4** and radical **5**. Thus, it should be possible to diminish the amount of rearranged product **4** if the radical **5** is formed in a medium containing a large excess of allyltributyltin. In fact, suppression of the unwanted rearranged product **4** was achieved when the dithiocarbonate **1** was slowly added (syringe pump) to a refluxing toluene solution of allyltributyltin (5 equiv.) and AIBN (0.3 equiv.). As a result, the yield of the desired compound **2** was improved to 60%, the only by-product being the 3-deoxy sugar **3**. However, because of the somewhat tedious nature of this procedure, especially for large-scale syntheses, we investigated the use of other 3-substituted precursors to GlcNAc-derivatives. We turned to the use of thionocarbonates, known to react slower than xanthates in radical deoxygenation reactions,[19] which should lower the radical concentration and so disfavor the unwanted rearrangement. Hence, thionocarbonates **8a–c** were prepared in quantitative yields by reaction of **7** with phenyl, tolyl, and *p*-fluorophenyl chlorothioformate in pyridine (Sch. 3).

The thionocarbonate sugars were subjected to radical coupling with allyltributyltin (5 equiv.) and AIBN (0.3 equiv.) in toluene at 80°C and 120°C (Table 1). Rearrangement of the thionocarbonate to thiocarbonate was never observed. (Furthermore, the stereochemistry of the allylation was again exclusively equatorial. The exclusive equatorial formation of the C–C bond is related to the $^4C_1$ chair conformation of the radical **5**, see Ref.[20]). At 120°C, compounds **8a** and **8b** gave similar yields of **2** (50%) with a slight improvement observed upon using **8c** (60%). The use of a lower temperature (80°C) resulted in an improved isolated yield of **2** (60%) when starting from **8a** and **8b**, but **8c** surprisingly gave a poorer result (30%). The by-product **3** derived from the reduction of



Scheme 3. Preparation of thionocarbonates **8a–c**.

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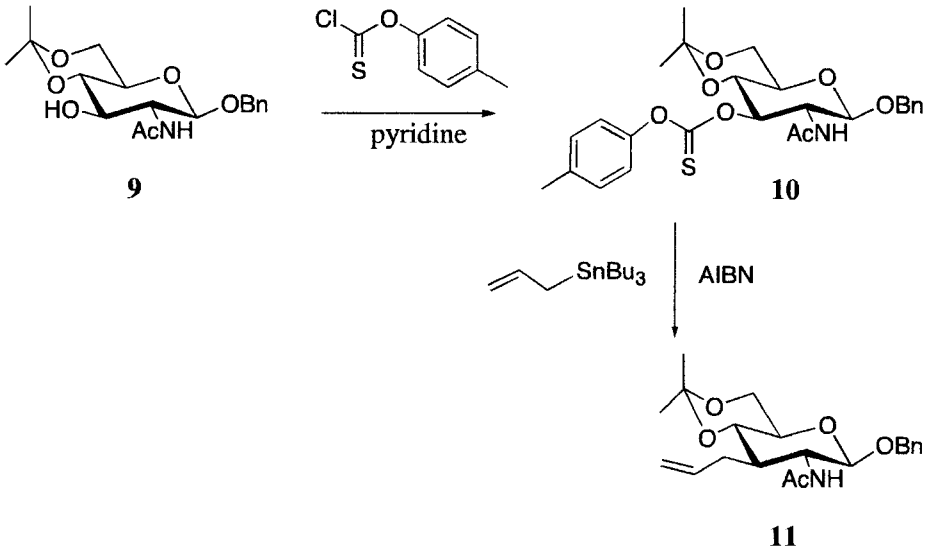
Table 1. Isolated yields of **2** upon AIBN-mediated radical coupling of **8a–c** and allyltributyltin in toluene.

Radical precursor	80°C (%)	120°C (%)
8a	60 (72[a])	50
8b	60	50
8c	30	60

[a]Refluxing benzene.



Scheme 4. AIBN-mediated radical coupling of xanthate **1** with allyltributyltin.

the radical intermediates could be limited by using benzene as the solvent instead of toluene (e.g., 72% yield of **2** from **8a**). However, formation of the reduced product **3** is not totally suppressed under these conditions (yield $<10\%$), suggesting the possibility of hydrogen abstraction from the acetamido group[a] or from the anomeric benzyl protecting group[10] by sugar radical **5**.

When applied to the β-derivative **10**, prepared from **9**[22] the above conditions lead to the allylic compound **11** in 60% yield. Again, total equatorial selectivity was observed (Sch. 4) as established by ^{1}H NMR spectroscopy. The ^{1}H NMR spectrum notably exhibited a large coupling constant for the H-2 signal ($J_{2,3} = 12.5$ Hz), indicating a trans-diaxial orientation of the C-2 and C-3 hydrogen atoms as expected for D-glucose adopting a $^4C_1$ conformation.

Having optimized the yield of the radical allylation, the route towards diene **13** was carried on by ozonolysis of **2** as described[7,8] (Sch. 5). Aldehyde **12** was then condensed

[a]Hydrogen abstraction from NH group by radical has already been hypothesized, see Ref.[21].

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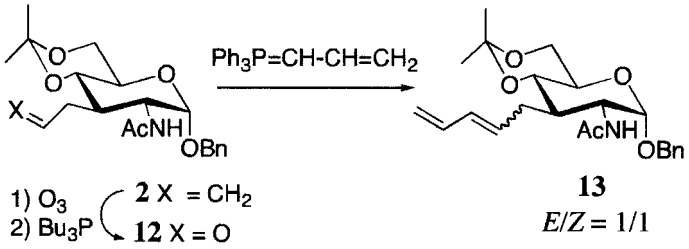
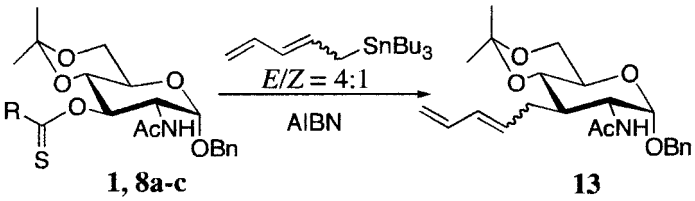


Scheme 5. Synthesis of diene **13** via a Wittig reaction.

with allylidenetriphenylphosphorane in a Wittig reaction affording, in 60% isolated yield, an inseparable 1 : 1 mixture of *E* and *Z* diene **13**.

Due to the poor selectivity of the Wittig reaction, we took advantage of the results obtained for the radical allylation and turned to the direct preparation of diene **13** using 2,4-pentadienyltributyltin.[23–25] Thus, dithiocarbonate **2** and thionocarbonates **8a–c** were reacted with 2,4-pentadienyltributyltin (5 equiv.) in toluene at 80°C in the presence of 0.3 equiv. of AIBN (Sch. 6, Table 2).

As in the case of allylation, the stereochemistry of the radical pentadienylation was exclusively equatorial ($J_{2,3} = 12.0$ Hz). Xanthate **1** afforded the dienyl derivatives as a 5 : 1 mixture of E/Z isomers in 50% yield. The thionocarbonates **8a** and **8c** afforded **13** in 70% yield, whereas the yield obtained with **8b** was lower (50%). In all cases, the only isolated by-product was the readily separable deoxy compound **3**. Once again, the yield was slightly enhanced when benzene was used as the solvent (75% from **8a**). Moreover, under these conditions, the three thionocarbonate derivatives afforded diene **13** in a 9 : 1 ratio of two isomers. The $J_{3',4'}$ value of the major one was 15.5 Hz, thus establishing that it was the *E*-isomer. Using **8a** as the radical donor, we found that running the reaction at 95°C gave the best yield (81%) of **13** but lowered the E/Z selectivity to 6.5 : 1. As can be seen from Table 2, the faster the radical is formed (from very reactive xanthate **1** or by increasing the temperature in the reaction involving **8a**), the poorer is the E/Z selectivity of the addition. This is the first example of diene synthesis from dithiocarbonate or thionocarbonate. While diene **13** seemed to be very pure by NMR analysis, we were unable to obtain good elemental analysis presumably because of traces of tin derivatives. The condensation product was thus characterized as its diacetate analog **15**. The latter was obtained in 97% yield by acid removal of the isopropylidene group in **13** affording **14**, which was acetylated with pyridine and acetic anhydride (Sch. 7).

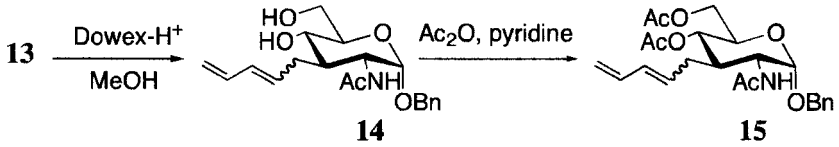


Scheme 6. Synthesis of diene **13** via AIBN-mediated radical coupling of **1** or **8a–c** with pentadienyltributyltin.

Table 2. Isolated yields of **13** upon the AIBN-mediated radical coupling of **1**, **8a–c**, and pentadienyltributyltin in toluene at 80°C (if not otherwise specified).

Radical precursor	Isolated yield (%)	Z/E
1 (R = CH_3S)	50	1 : 5
8a (R = PhO)	70 (75[a])	1 : 9
	81[b]	1 : 6.5
8b (R = $p$$CH_3$PhO)	50	1 : 9
8c (R = pFPhO)	70	1 : 9

[a]Refluxing benzene.
[b]Toluene, 95°C.



Scheme 7. Synthesis of acetylated diene **15**.

CONCLUSION

We have shown that the radical alkenylation at position 3 of GlcNAc derivatives can be improved using thiocarbonates rather than dithiocarbonate as radical donors. The allylic compounds **2** and **11** were isolated as pure compounds in 60% yield since formation of the rearranged product derived from xanthate **1** could be suppressed. The diene **13** was obtained in multigram quantities with good E/Z selectivity and good yield using this straightforward method. These *C*-branched alkenyl derivatives will be used for the synthesis of more complex *C*-glycosides.

EXPERIMENTAL

General

Melting points were determined with a capillary apparatus and are uncorrected. Optical rotations were measured at 28°C ± 2°C. IR spectra were recorded as KBr pellets. NMR spectra were recorded at r.t. with Bruker AC 200 or AC 250 spectrometers. Mass spectrometry was recorded on a MAT 95S instrument. Elemental analyses were performed at the CNRS Microanalytical Laboratory (Gif sur Yvette, France). All moisture-sensitive reactions were performed under an argon atmosphere using oven-dried glassware. All solvents were dried over standard drying agents and freshly distilled prior to use. Flash column chromatography was performed with Silica Gel 60A C.C. (6–35 μm, SDS). The reactions were monitored by TLC using Silica Gel 60 F_{254} with detection by UV light (254 nm) and by charring with sulfuric acid.

General Procedure for the Preparation of Thionocarbonates 8a–c

To a solution of **7** (1.06 g, 5.7 mmol) in dry pyridine (10 mL) was added phenyl, tolyl, or *p*-fluorophenyl chlorothioformate (6.8 mmol, 1.2 equiv.). The reaction was kept at r.t. for 12 hr. After evaporation of the solvent under reduced pressure (bath temperature not exceeding 40°C), the residue was partitioned into CH_2Cl_2–water. The organic phase was concentrated and the residue was purified by flash chromatography to give the target products in quantitative yields. Solvents for chromatography, and analytical data are shown below.

Benzyl 2-acetamido-2-deoxy-4,6-*O*-isopropylidene-3-*O*-(phenylthioformate)-α-D-glucopyranoside (8a).[12] Flash chromatography (EtOAc–toluene, 1 : 2). ^{1}H and ^{13}C NMR spectra were identical to those described.[12] $[\alpha]_D$ +42 (*c* 1, CH_2Cl_2); lit.[12] $[\alpha]_D$ +31 (*c* 0.4, $CHCl_3$); m.p. 164°C (EtOAc, petroleum ether), lit.[12] m.p. 158–162°C.

Benzyl 2-acetamido-2-deoxy-4,6-*O*-isopropylidene-3-*O*-(*p*-tolylthioformate)-α-D-glucopyranoside (8b). Flash chromatography (EtOAc–toluene 1 : 4→2 : 1). $[\alpha]_D$ + 30 (*c* 1, CH_2Cl_2); m.p. 58°C (EtOAc, petroleum ether), IR: 3437, 3065, 3039, 2995, 2938, 2912, 2882, 2868, 1756, 1667, 1503, 1454, 1382, 1263, 1105, 1079, 860 cm^{-1}. ^{1}H NMR ($CDCl_3$, 250 MHz) δ: 7.42–7.27 (m, 5H, Ar), 7.22–7.10 (m, 2H, Ar), 7.00–6.92 (m, 2H, Ar), 5.85 (d, 1H, J = 10.0 Hz, N*H*), 5.77 (dd, 1H, J = 10.5, 11.0 Hz, H-3), 4.89 (d, 1H, J = 4.0 Hz, H-1), 4.72 (d, 1H, J = 13.0 Hz, CH_2), 4.48 (d, 1H, J = 13.0 Hz, CH_2), 4.46 (ddd, 1H J = 4.0, 10.0, 10.5 Hz, H-2), 3.91 (ddd, 1H, J = 3.5, 5.5, 10.0 Hz, H-5), 3.75–3.87 (m, 3H, H-4, H-6a, and H-6b), 2.34 (s, 3H, PhCH_3), 1.90 (s, 3H, NHCOCH_3), 1.48 and 1.41 (2s, 6H, 2CH_3). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 196.1, 169.8, 151.1, 136.5, 136.2, 129.9, 129.8, 128.5, 128.2, 128.0, 127.9, 121.2, 120.5, 99.9, 97.1, 80.4, 71.7, 69.8, 63.8, 62.1, 60.3, 52.7, 28.9, 23.2, 20.8, 18.9, 14.0. HRMS (ESI): m/z calcd for $[C_{26}H_{31}NO_7S + Na]^+$: 524.1719. Found 524.1719.

Anal. Calcd for $C_{26}H_{31}NO_7S$: C, 62.26; H, 6.23; N, 2.79. Found: C, 62.25; H, 6.48; N, 2.84.

Benzyl 2-acetamido-2-deoxy-3-*O*-(*p*-fluorophenylthioformate)-4,6-*O*-isopropylidene-α-D-glucopyranoside (8c). Flash chromatography (EtOAc–toluene 1 : 3); $[\alpha]_D$ + 28 (*c* 1, CH_2Cl_2); m.p. 151°C (EtOAc, petroleum ether); IR: 3435, 3283, 3075, 2996, 2937, 2915, 2883, 2869, 1676, 1500, 1382, 1260, 1192, 1080, 1052, 1009 cm^{-1}. ^{1}H NMR ($CDCl_3$, 250 MHz) δ: 7.45–7.30 (m, 5H, Ar), 7.15–7.00 (m, 4H, Ar), 5.83 (d, 1H, J = 9.0 Hz, N*H*), 5.77 (dd, 1H, J = 9.0, 10.5 Hz, H-3), 4.91 (d, 1H, J = 4.0 Hz, H-1), 4.76 (d, 1H, J = 12.0 Hz, CH_2), 4.53 (d, 1H, J = 12.0 Hz, CH_2), 4.48 (ddd, 1H, J = 4.0, 10.0, 10.5 Hz, H-2), 3.91 (ddd, 1H, J = 3.5, 5.5, 10.0 Hz, H-5), 3.75–3.87 (m, 3H, H-4, H-6a, and H-6b), 1.92 (s, 3H, NHCOCH_3), 1.50 and 1.43 (2s, 6H, 2CH_3). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 195.8, 169.8, 160.6 (d, $^1J_{C-F}$ = 246 Hz), 149.1, 136.5, 128.6, 128.3, 128.1, 123.1 (d, $^3J_{C-F}$ = 8 Hz), 117.6 (d, $^2J_{C-F}$ = 23 Hz), 100.0, 97.6, 80.9, 71.7, 69.9, 63.9, 62.2, 52.7, 29.0, 23.3, 18.9. HRMS (ESI): m/z calcd for $[C_{25}H_{28}FNO_7S + Na]^+$: 528.1468. Found 528.1468.

Anal. Calcd for $C_{25}H_{28}FNO_7S$: C, 59.39; H, 5.58; N, 2.77. Found: C, 59.35; H, 5.53; N, 3.06.

Benzyl 2-acetamido-2-deoxy-4,6-*O*-isopropylidene-3-*O*-(*p*-tolylthioformate)-β-D-glucopyranoside (10). Treatment of **9** (0.4 g, 1.13 mmol) in dry pyridine (2.4 mL) with *p*-tolylchlorothioformate (176 μL, 1.3 equiv.) as described for **8a–c** gave, after flash chromatography (EtOAc–toluene 1 : 4), compound **10** (477 mg, 85%). $[\alpha]_D$ −123

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(c 1, CH_2Cl_2); m.p. 158°C (EtOAc, petroleum ether), IR: 3290, 3089, 3031, 2994, 2945, 2880, 1654, 1560, 1506, 1374, 1290, 1221, 1198, 1091, 1039, 855, 698 cm^{-1}. ^1H NMR ($CDCl_3$, 250 MHz) δ: 7.26–7.40 (m, 5H, Ar), 7.14–7.25 (m, 2H, Ar), 6.92–7.00 (m, 2H, Ar), 5.72 (dd, 1H, $J = 10.5$, 10.0 Hz, H-3), 5.57 (d, 1H, $J = 10.0$ Hz, N*H*COCH$_3$), 4.91 (d, 1H, $J = 13.0$ Hz, PhC*H*$_2$), 4.67 (d, 1H, $J = 9.0$ Hz, H-1), 4.61 (d, 1H, $J = 13.0$ Hz, PhC*H*$_2$), 4.19 (dt, 1H, $J = 10.0$, 9.0 Hz, H-2), 4.15 (dd, 1H, $J = 11.5$, 6.0 Hz, H-6a), 3.92 (t, 1H, $J = 10.5$, H-4), 3.86 (dd, 1H, $J = 10.5$, 11.5 Hz, H-6b), 3.39 (dt, 1H, $J = 10.5$, 6.0 Hz, H-5), 2.37 (s, 3H, PhC*H*$_3$), 1.94 (s, 3H, NHCOC*H*$_3$), 1.52 and 1.43 (2s, 6H, 2CH$_3$). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 196.1, 170.0, 151.2, 136.9, 136.4, 129.9, 128.4, 127.9, 127.9, 121.2, 100.2, 99.8, 81.6, 71.6, 70.7, 67.0, 62.0, 55.2, 30.8, 28.9, 23.4, 20.9, 18.9. HRMS (ESI): m/z calcd for $[C_{26}H_{31}NO_7S + Na]^+$: 524.1719. Found 524.1720.

Anal. Calcd for $C_{26}H_{31}NO_7S$: C, 62.26; H, 6.23; N, 2.79. Found: C, 62.39; H, 6.35; N, 2.81.

Benzyl 2-acetamido-3-*C*-allyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside (2). A solution of **8c** (200 mg, 0.39 mmol), allyltributyltin (580 μL, 2 mmol), and AIBN (19.5 mg, 0.12 mmol) in 1.6 mL of anhyd. degassed toluene was heated at 120°C under argon for 6 hr (complete disappearance of the starting material by TLC analysis CH_2Cl_2–MeOH 9 : 1). The solution was concentrated and the residue purified by flash chromatography (EtOAc–toluene 2 : 3). Eluted first was **2**[7,8] (90 mg, 60%).

Eluted second was compound **3** (39 mg, 30%).[12] This compound proved spectroscopically identical to the one described[12] but the optical rotation differed considerably. $[\alpha]_D$ +113 (c 0.3, $CHCl_3$), lit.[12] $[\alpha]_D$ +42 (c 0.3, $CHCl_3$).

When the reaction was conducted with xanthate **1**, eluted first was compound **4** (15%) (this compound was contaminated by ~10% of **2**). ^1H NMR ($CDCl_3$, 250 MHz) δ: 7.44–7.27 (m, 5H, Ar), 5.87 (d, 1H, $J = 10.0$ Hz, NH), 4.86 (d, 1H, $J = 3.5$ Hz, H-1), 4.74 (d, 1H, $J = 12.5$ Hz, PhC*H*$_2$), 4.44 (d, 1H, $J = 12.5$ Hz, PhC*H*$_2$), 4.27 (ddd, $J = 3.8$, 10.0, 12.0 Hz, H-5), 3.99 (t, 1H, $J = 11.5$ Hz, H-3), 3.88–3.54 (m, 4H, H-2, H-4, H-6a, H-6b), 2.42 (s, 3H, SC*H*$_3$), 1.89 (s, 3H, COC*H*$_3$), 1.46 (s, 3H, C*H*$_3$), 1.41 (s, 3H, C*H*$_3$). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 169.7, 169.5, 136.7, 128.15, 128.1, 128.0, 99.4, 96.8, 70.6, 69.7, 65.9, 64.9, 62.5, 53.0, 46.6, 28.9, 22.9, 18.9, 13.29. MS (ESI): m/z 464.2 ($M + Na^+$). HRMS (ESI): m/z calcd for $[C_{20}H_{27}NO_6S_2 + Na]^+$: 464.1177. Found 464.1178.

Benzyl 2-acetamido-3-*C*-allyl-2,3-dideoxy-4,6-*O*-isopropylidene-β-D-glucopyranoside (11). A solution of **10** (200 mg, 0.4 mmol), allyltributyltin (620 μL, 2 mmol), and AIBN (19.5 mg, 0.3 equiv.) in 1.6 mL of anhyd. degassed toluene was treated as described for the preparation of **2**. Flash chromatography (EtOAc–toluene 1 : 2) gave **11** (91 mg, 60%). $[\alpha]_D$ −69 (c 1, CH_2Cl_2); m.p. 177°C (EtOAc, petroleum ether); IR: 3343, 3060, 3031, 3001, 2945, 2896, 1677, 1535, 1373, 1263, 1209, 1198, 1167, 1080, 1023, 918, 852, 753, 703, 589 cm^{-1}. ^1H NMR ($CDCl_3$, 250 MHz) δ: 7.38–7.27 (m, 5H, Ar), 5.92–5.68 (m, 1H, C*H* = CH$_2$), 5.16 (d, 1H, $J = 10.0$ Hz, N*H*COCH$_3$), 5.04 (t, 2H, CH = C*H*$_2$), 4.87 (d, 1H, $J = 13.0$ Hz, PhC*H*$_2$), 4.57 (d, 1H, $J = 13.0$ Hz, PhC*H*$_2$), 4.50 (d, 1H, $J = 9.0$ Hz, H-1), 3.93 (dd, 1H, $J = 11.5$, 5.5 Hz, H-6a), 3.80 (ddd, 1H, $J = 12.5$, 10.0, 9.0 Hz, H-2), 3.77 (t, 1H, $J = 11.5$, H-6b), 3.45 (dd, 1H, $J = 10.5$, 10.0 Hz, H-4), 3.30 (ddd, 1H, $J = 11.5$, 10.5, 5.5 Hz, H-5), 2.12–2.39 (m, 2H, C*H*$_2$CH = CH$_2$), 1.95 (s, 3H, NHCOC*H*$_3$), 1.94–1.80 (m, 1H, H-3), 1.40 and 1.46 (2s, 6H, 2C*H*$_3$). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 169.7, 137.4, 134.1, 128.5, 128.4, 127.9, 127.8, 117.8,

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101.3, 99.4, 70.3, 62.6, 52.6, 43.03, 30.3, 29.1, 23.4, 18.9. HRMS (ESI): m/z calcd for $[C_{21}H_{29}NO_5 + Na]^+$: 398.1943. Found 398.1942.

Anal. Calcd for $C_{21}H_{29}NO_5$: C, 67.18; H, 7.79; N, 3.73; O, 21.31. Found: C, 67.23; H, 7.83; N, 3.67; O, 21.53.

Benzyl 2-acetamido-2,3-dideoxy-4,6-*O*-isopropylidene-3-*C*-(1′-penta-2′,4′-dienyl)-α-D-glucopyranoside (13). A solution of **8a** (18 g, 37 mmol), pentadienyltributyltin (66.2 g, 185.3 mmol), and AIBN (1.8 g, 11.1 mmol) in 200 mL of anhyd. degassed toluene was heated at 95°C for 3 hr (complete disappearance of the starting material by TLC analysis CH_2Cl_2–MeOH 9 : 1). The solution was concentrated and the residue purified by flash chromatography (CH_2Cl_2/acetone 100 : 3) to afford a 6.5 : 1 E/Z mixture of diene **13** (12 g, 81%). Spectroscopic data for ***E*-13**: ^{1}H NMR ($CDCl_3$, 250 MHz) δ: 7.42–7.27 (m, 5H, Ar), 6.33 (dt, 1H, $J = 10.5$, 17.5 Hz, H-4′), 6.04 (dd, 1H, $J = 10.5$, 15.5 Hz, H-3′), 5.73 (ddd, 1H, $J = 7.0$, 8.5, 15.5 Hz, H-2′), 5.58 (d, 1H, $J = 10.0$ Hz, N*H*), 5.10 (dd, 1H, $J = 17.5$, 1.5 Hz, H-5a′), 4.97 (dd, 1H, $J = 1.5$, 10.0 Hz, H-5b′), 4.74 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.73 (d, 1H, $J = 3.5$ Hz, H-1), 4.44 (d, 1H, PhCH_2), 4.18 (ddd, 1H, $J = 3.5$, 10.0, 12.0 Hz, H-2), 3.90–3.63 (m, 3H, H-5, H-6a, H-6b), 3.50–3.38 (m, 1H, H-4), 2.40–2.20 (m, 2H, H-1a′, H-1b′), 1.93 (s, 3H, COCH_3), 2.03–1.87 (m, 1H, H-3), 1.44 and 1.42 (2s, 6H, 2CH_3). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 169.5, 137.1, 136.9, 133.8, 130.7, 128.5, 128.0, 115.2, 99.4, 96.6, 70.9, 69.4, 64.9, 62.8, 50.0, 40.01, 29.2, 29.0, 23.2, 19.0. HRMS (ESI): m/z calcd for $[C_{23}H_{31}O_5N + Na]^+$: 424.2100. Found 424.2092.

Benzyl 2-acetamido-2,3-dideoxy-3-*C*-(1′-penta-2′,4′-dienyl)-α-D-glucopyranoside (14). To a solution of **13** (E/Z 9 : 1, 406 mg, 1.01 mmol) in methanol (5 mL) Dowex 50X8-200 H^+ (400 mg) was added. The mixture was heated at 60°C for 4 hr and then diluted with CH_2Cl_2/MeOH (1 : 1, 5 mL) and filtered. The solution was concentrated to afford a white powder which was washed with petroleum ether to afford **14** (E/Z 9 : 1, 357 mg, 98%). Spectroscopic data for ***E*-14**: ^{1}H NMR ($CDCl_3 + 1$ drop CD_3OD, 250 MHz) δ: 7.41–7.26 (m, 5H, Ar), 7.01 (d, 1H, $J = 9.5$ Hz, N*H*), 6.30 (dt, 1H, $J = 10.5$, 17.0 Hz, H-4′), 6.08 (dd, 1H, $J = 10.5$, 15.5 Hz, H-3′), 5.70 (dt, 1H, $J = 7.0$, 15.5 Hz, H-2′), 5.07 (dd, 1H, $J = 17.0$, 1.5 Hz, H-5a′), 4.95 (dd, 1H, $J = 1.5$, 10.5 Hz, H-5b′), 4.75 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.75 (d, 1H, $J = 3.5$ Hz, H-1), 4.47 (d, 1H, $J = 12.0$ Hz, PhCH_2), 3.97 (ddd, 1H, $J = 12.0$, 9.5, 3.5 Hz, H-2), 3.79 (dd, 1H, $J = 12.0$, 3.5 Hz, H-6a), 3.73 (dd, 1H, $J = 12.0$, 4.0 Hz, H-6b), 3.63 (ddd, 1H, $J = 10.0$, 4.0, 3.5 Hz, H-5), 3.40 (t, 1H, $J = 10.0$ Hz, H-4), 2.31–2.40 (m, 2H, H-1a′, H-1b′), 1.93 (s, 3H, COCH_3), 2.05–1.87 (m, 1H, H-3), 1.93 (s, 3H, COCH_3). ^{13}C NMR (d_6-DMSO, 63 MHz), δ: 168.9, 138.0, 137.2, 133.0, 131.4, 128.1, 127.6, 127.4, 115.1, 95.2, 73.7, 67.6, 66.0, 60.9, 49.3, 49.3, 29.1, 22.3.

Anal. Calcd for $C_{20}H_{27}NO_5 \cdot 0.3H_2O$: C, 65.48; H, 7.58; N, 3.82; O, 23.12. Found: C, 65.61; H, 7.45; N, 3.73; O, 23.11.

Benzyl 2-acetamido-4,6 di-*O*-acetyl-2,3-dideoxy-3-*C*-(1′-penta-2′,4′-dienyl)-α-D-glucopyranoside (15). To a solution of **14** (300 mg, 0.83 mmol) in pyridine (5 mL) 390 μL of acetic anhydride was added. After one night, the mixture was concentrated and the residue was purified by flash chromatography (toluene/acetone 3 : 1) to afford a 9 : 1 E/Z mixture of diene **15** (366 mg, 99%). Spectroscopic data for ***E*-15**: ^{1}H NMR ($CDCl_3$, 250 MHz) δ: 7.41–7.26 (m, 5H, Ar), 6.23 (dt, 1H, $J = 10.5$, 17.0 Hz, H-4′), 5.93 (dd, 1H, $J = 10.5$, 15.5 Hz, H-3′), 5.55 (dt, 1H, $J = 7.0$, 15.5 Hz, H-2′), 5.53 (d, 1H, $J = 10.0$ Hz, N*H*), 5.06 (dd, 1H, $J = 17.0$, 1.5 Hz, H-5a′), 4.94 (dd, 1H, $J = 1.5$, 10.5 Hz, H-5b′), 4.86 (t, 1H, $J = 10.0$ Hz, H-4), 4.76 (d, 1H, $J = 3.5$ Hz, H-1), 4.70

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(d, 1H, $J = 12.0$ Hz, PhCH_2), 4.46 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.14 (dd, 1H, $J = 12.0$, 5.0 Hz, H-6a), 4.13 (ddd, 1H, $J = 12.0$, 10.0, 3.5 Hz, H-2), 4.96 (dd, 1H, $J = 12.0$, 2.0 Hz, H-6b), 4.88 (ddd, 1H, $J = 10.0$, 5.0, 2.0 Hz, H-5), 2.33–2.10 (m, 3H, H-3, H-1′a, H-1′b), 2.03 (s, 3H, NHCOCH_3), 1.96 (s, 3H, COCH_3), 1.89 (s, 3H, COCH_3). ^{13}C NMR ($CDCl_3$, 63 MHz) δ: 170.7, 169.7, 169.6, 136.9, 136.7, 132.5, 131.5, 131.4, 128.6, 128.2, 128.1, 115.8, 96.1, 69.7, 69.2, 68.7, 62.5, 50.3, 40.4, 31.7, 23.2, 20.8, 20.7. HRMS (ESI): m/z calcd for $[C_{24}H_{31}NO_7 + Na]^+$: 468.1998. Found 468.2007.

Anal. Calcd for $C_{24}H_{31}NO_7$: C, 64.70; H, 7.01; N, 3.14; O, 25.14. Found: C, 64.48; H, 7.03; N, 3.03; O, 25.33.

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REFERENCES

1. Du, Y.; Linhardt, R.J.; Vlahov, I.R. Recent advances in stereoselective *C*-glycoside synthesis. Tetrahedron **1998**, *54*, 9913–9959.
2. Togo, H.; He, W.; Waki, Y.; Yokoyama, M. *C*-glycosidation technology with free radical reactions. Synlett. **1998**, 700–717.
3. Postema, M.H.D. *C-Glycosides Synthesis*; CRC Press: Boca Raton, 1995.
4. Levy, D.; Tang, C. *The Chemistry of C-Glycosides*; Elsevier/Pergamon: Oxford, 1995.
5. Beau, J.-M.; Gallagher, T. Nucleophilic C-glycosyl donors for *C*-glycoside synthesis. Top. Curr. Chem. **1997**, *187*, 1–54.
6. Beau, J.-M.; Vauzeilles, B.; Skrydstrup, T. *C*-glycosyl compounds as stable analogs of natural oligosaccharides and glycosyl aminoacids, in glycoscience. In *Chemistry and Chemical Biology*; Fraser-Reid, B., Tatsuta, K., Thiem, J., Eds.; Springer Verlag: Heidelberg, 2001; Vol. 3, 2679–2724.
7. Sutherlin, D.P.; Armstrong, R.W. The synthesis of *C*-trisaccharides exploiting the stereochemical diversity of a central sugar. J. Am. Chem. Soc. **1996**, *118*, 9802–9803.
8. Sutherlin, D.P.; Armstrong, R.W. Synthesis of 12 stereochemically and structurally diverse *C*-trisaccharides. J. Org. Chem. **1997**, *62*, 5267–5283.
9. Liu, L.; Postema, M.H.D. A unified approach to differentially linked β-*C*-disaccharides by ring-closing metathesis. J. Am. Chem. Soc. **2001**, *123*, 8602–8603.
10. Postema, M.H.D.; Piper, J.L.; Liu, L.; Shen, J.; Faust, M.; Andreana, P. Synthesis and partial biological evaluation of a small library of differentially-linked β-*C*-disaccharides. J. Org. Chem. **2003**, *68*, 4748–4754.
11. Lubineau, A.; Grand, E.; Scherrmann, M.-C. New access to *C*-disaccharide analogs of α,α-trehalose using aqueous hetero Diels-Alder reaction. Carbohydr. Res. **1997**, *297*, 169–174.

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12. Ledvina, M.; Pavelova, R.; Rohlenova, A.; Jezek, J.; Saman, D. Synthesis of normuramic acid carba analog and its glycopeptide derivative resistant to β-elimination splitting of the side chain. Collect. Czech. Chem. Commun. **2000**, *65*, 1726–1736.
13. Schönberg, A.; Vargha, L. Organic sulfur compounds. XVI. (Thermal) rearrangement of thionocarbonic esters into thiolcarbonic esters. Chem. Ber. **1930**, *63B*, 178–180.
14. Freudenberg, K.; Wolf, A. Acetone-sugar. X. 3-Thioglucose. Chem. Ber. **1927**, *60B*, 232–238.
15. Nayak, U.G.; Whistler, R.L. Nucleophilic displacement in 1,2:5,6-di-*O*-isopropylidene-3-*O*-(*p*-tolylsulfonyl)-α-D-glucofuranose. J. Org. Chem. **1969**, *34*, 3819–3822.
16. Quiclet-Sire, B.; Zard, S.Z. A practical modification of Barton-McCombie reaction and radical *O*- to *S*-rearrangement of xanthates. Tetrahedron Lett. **1998**, *39*, 9435–9438.
17. Barton, D.H.R.; Choi, S.-Y. An efficient rearrangement of secondary alkyl *S*-methyl xanthates by trimethylaluminum (TMA). Tetrahedron Lett. **1996**, *37*, 2695–2698.
18. Marco-Contelles, J.; Ruiz-Fernández, P.; Sánchez, B. A new annulated furanoses: a new free-radical isomerization of an *S*-methyl hex-5-enylxanthate to an *S*-(cyclopentylmethyl) *S*-methyl dithiocarbonate. J. Org. Chem. **1993**, *58*, 2894–2898.
19. Barton, D.H.R.; Dorchak, J.; Jaszberenyi, J.Cs. The invention of radical reactions. Part XXIV. Relative rates of acylation and radical deoxygenation of secondary alcohols. Tetrahedron **1992**, *48*, 7435–7446.
20. Korth, H.-G.; Sustmann, R.; Gröninger, K.S.; Witzel, T.; Giese, B. Electron spin resonance spectroscopic investigation of carbohydrate radicals. Part 3. Conformation in deoxypyranosan-2-, -3-, and -4-yl radicals. J. Chem. Soc. Perkin Trans. II **1986**, 1461–1464.
21. Oba, M.; Nishiyama, K. Radical-based deoxygenation of aliphatic alcohols via thioxocarbamate derivatives. Tetrahedron **1994**, *50*, 10193–10200.
22. Hasegawa, A.; Fletcher Jr., H.G. The behavior of some aldoses with 2,2-dimethoxypropane-*N*,*N*-dimethylformamide-*p*-toluenesulfonic acid. I. At room termperature (~25°C). Carbohydr. Res. **1973**, *29*, 209–222.
23. De los Angeles Paz-Sandoval, M.; Powell, P. Diene and dienyl complexes of transition elements IV η^5-pentadienyltricarbonylrhenium. J. Organomet. Chem. **1981**, *219*, 81–83.
24. Watanabe, Y.; Yoneda, T.; Okumura, T.; Ueno, Y.; Toru, T. Convenient radical α-monoallylations of carbonyl compounds. Bull. Chem. Soc. Jpn. **1993**, *66*, 3030–3033.
25. Landais, Y.; Planchenault, D. Radical allylation of α-silyl acetic esters. Tetrahedron **1995**, *51*, 12097–12108.

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