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Synthetic Methods

Chemoselective and Direct Functionalization of Methyl Benzyl Ethers and Unsymmetrical Dibenzyl Ethers by Using Iron Trichloride

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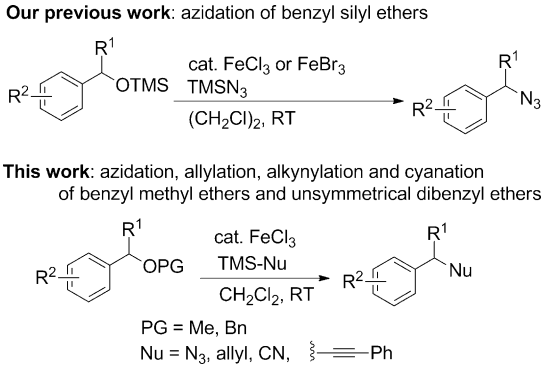
Abstract: Methyl and benzyl ethers are widely utilized as protected alcohols due to their chemical stability, such as the low reactivity of the methoxy and benzyloxy groups as leaving groups under nucleophilic conditions. We have established the direct azidation of chemically stable methyl and benzyl ethers derived from secondary and tertiary benzyl alcohols. The present azidation chemoselectively proceeds at the secondary or tertiary benzylic positions of methyl benzyl ethers or unsymmetrical dibenzyl ethers and is also applicable to direct allylation, alkynylation, and cyanation reactions, as well as the azidation. The present methodologies provide not only a novel chemoselectivity but also the advantage of shortened synthetic steps, due to the direct process without the deprotection of the methyl and benzyl ethers.

Introduction

The nucleophilic substitution of protected alcohols is usually incomplete without further multiple synthetic steps, such as deprotection to yield free alcohols and refunctionalization to form chemically reactive functional groups (such as triflate, tosylate, halogen, etc.), so the direct conversion of protected alcohols would be an efficient and straightforward method possessing the advantage of shortening the synthetic process. Methyl ethers (ROMe) and benzyl ethers (ROBn) are widely utilized as protected alcohols due to their chemical stability, such as the low reactivity of the methoxy and benzyloxy groups as leaving groups.[1] Only limited methods of C–C bond formations by using allyl boranes,[2] allyl silanes,[3] silyl enolates,[4] or arenes[5] and aminations by using chlorosulfonyl isocyanate[6] with methyl ethers or benzyl ethers have been reported. We recently reported that the combination of an iron or gold catalyst and silicon reagents was effective to activate the carbon–oxygen bond of various complicated substrates,[7,8] and a direct azidation method with benzyl silyl ethers was established (Scheme 1).[8] Herein, we report the direct azidation of chemically stable methyl and benzyl ethers derived from secondary and tertiary benzyl alcohols.[9] This method is adapted to chemoselective azidation at the secondary benzylic position of the methyl benzyl or unsymmetrical dibenzyl ethers. Furthermore, the present methodology is also applicable for the direct allylation, alkynylation, and cyanation of methyl or benzyl ethers.[10,11]



Scheme 1. Direct functionalizations of protected benzyl alcohols. TMS: trimethylsilyl; PG: protecting group; Bn: benzyl; Nu: nucleophile.

Results and Discussion

First of all, we examined the direct azidation of methyl ethers. Although the methyl group is a versatile protective group of alcohols that tolerates nucleophilic conditions, harsh acidic conditions are required for the cleavage of the methyl ether to give free hydroxy groups due to its stability.[1] Therefore, the development of efficient and direct functionalization methods would contribute to expand the availability of methyl ethers. The efficiency of Lewis acids as catalysts and various azido sources was investigated by using benzhydrol methyl ether (**1a**) as a substrate in CH_2Cl_2 at room temperature (Table 1).

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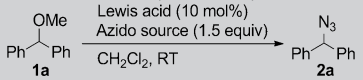
Table 1. Direct azidation of benzhydrol methyl ether (**1a**).[a]

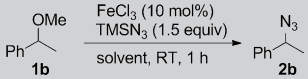


Entry	Lewis acid	Azido source	Solvent	Time	Yield **1a**/**2a** [%]
1	$FeCl_3$	$TMSN_3$	CH_2Cl_2	5 min	0/93
2[b]	$FeCl_3$	$TMSN_3$	CH_2Cl_2	5 min	0/94
3	$FeBr_3$	$TMSN_3$	CH_2Cl_2	5 min	0/93
4	$AuCl_3$	$TMSN_3$	CH_2Cl_2	5 min	0/99
5	$FeCl_2{\cdot}4H_2O$	$TMSN_3$	CH_2Cl_2	3 h	79/11
6	$Fe(acac)_3$	$TMSN_3$	CH_2Cl_2	3 h	no reaction
7	$InCl_3$	$TMSN_3$	CH_2Cl_2	3 h	0/93
8	TMSOTf	$TMSN_3$	CH_2Cl_2	3 h	0/93
9	$SnCl_2$	$TMSN_3$	CH_2Cl_2	3 h	33/63
10	$BF_3{\cdot}Et_2O$	$TMSN_3$	CH_2Cl_2	3 h	80/10
11	$FeCl_3$	$TMSN_3$	$(CH_2Cl)_2$	15 min	5/94
12	$FeCl_3$	$TMSN_3$	$CHCl_3$	15 min	14/76
13	$FeCl_3$	$TMSN_3$	toluene	5 min	0/97
14	$FeCl_3$	$TMSN_3$	THF	3 h	no reaction
15	$FeCl_3$	DPPA	CH_2Cl_2	3 h	53/trace
16	$FeCl_3$	NaN_3	CH_2Cl_2	3 h	78/13

[a] acac: Acetylacetonate; OTf: trifluoromethanesulfonate; THF: tetrahydrofuran; DPPA: diphenylphospholyl azide; [b] 5 mol% of $FeCl_3$ was used.

Whereas the use of $FeCl_3$, $FeBr_3$, or $AuCl_3$ (5–10 mol%) in the presence of $TMSN_3$ (1.5 equiv) could facilitate the desired azidation to give the corresponding azido product (**2a**) in excellent yield within 5 min (Table 1, entries 1–4), $FeCl_2{\cdot}4H_2O$ and $Fe(acac)_3$ were ineffective as alternative iron catalysts for the present azidation (Table 1, entries 5 and 6). Among other traditional Lewis acids (Table 1, entries 7–10), TMSOTf or $InCl_3$ also effectively catalyzed the present azidation; however, a prolongation of the reaction time (3 h) was required (Table 1, entries 7 and 8). The azidation proceeded smoothly in CH_2Cl_2, $(CH_2Cl)_2$, $CHCl_3$, or toluene, but not in THF (Table 1, entries 11–14), so we re-examined the solvent efficiency by using 1-phenylethanol methyl ether (**1b**) in CH_2Cl_2, $(CH_2Cl)_2$, or toluene (Table 2). Consequently, CH_2Cl_2 was determined to be most effective as the solvent. $TMSN_3$ was found to be an efficient azido source in comparison with DPPA and NaN_3, which gave very low conversion efficiencies (Table 1, entry 1 versus entries 15 and 16).

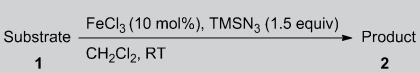
Table 2. Retest of solvent efficiency by using 1-phenylethanol methyl ether (**1b**).



Entry	Solvent	Yield **2a** [%]
1	CH_2Cl_2	74
2	$(CH_2Cl)_2$	49
3	toluene	59

We next investigated the direct azidation of various methyl ethers by using $FeCl_3$ as an inexpensive and widely used catalyst (Table 3). 1-Arylethanol methyl ethers **1b–d**, bearing an electron-donating or -withdrawing group on the aromatic ring, and 1-indanol methyl ether (**1e**) were effectively transformed into the corresponding azido products **2b–e** in high yields (Table 3, entries 1–4). The azidation of the allyl and propargyl alcohol methyl ethers **1f** and **1g** also provided the corresponding allylic and propargylic azides **2f**[12] and **2g**, respectively (Table 3, entries 5 and 6). The benzylic methyl ether **1h**, bearing an alkyl chloride within the same molecule, chemoselectively underwent the iron-catalyzed azidation at the benzyl position without any influence on the alkyl chloride functionality (Table 3, entry 7). The tertiary benzyl methyl ethers **1i** and **1j** were effectively converted into the azido products **2i** and **2j** in excellent yields, regardless of the bulkiness (Table 3, entries 8 and 9). However, the azidation of benzyl methyl ether (**1k**), derived from the primary benzyl alcohol, and 2-decyl methyl ether (**1l**), derived from the aliphatic alcohol, never proceeded (Table 3, entries 10 and 11). The chemoselective azidation of secondary benzylic methyl ethers **1m** and **1n** was

Table 3. Scope of substrates for the direct azidation of methyl benzyl ethers.

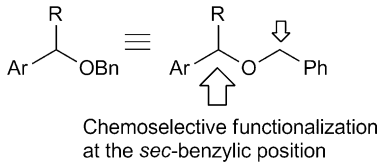


Entry	Substrate (**1**)	Product (**2**)	Time	Yield [%]
1	R: H; **1b**	**2b**	1 h	74
2	R: MeO; **1c**	**2c**	1 h	72
3	R: Cl; **1d**	**2d**	1 h	86
4	**1e**	**2e**	5 min	89
5	**1f**	**2f**	5 min	91
6	**1g**	**2g**	2 h	35[a]
7[b]	**1h**	**2h**	2 h	75
8	**1j**	**2j**	30 min	97
9	**1i**	**2i**	15 min	89
10	**1k**	**2k**	2 h	no reaction
11	**1l**	**2l**	2 h	no reaction
12[c]	**1m**	**2m**	5 min	87
13[c]	**1n**	**2n**	4 h	85

[a] 32% of starting material was recovered; [b] 30 mol% of $FeBr_3$ was used; [c] 30 mol% of $FeCl_3$ was used.

successfully accomplished in the presence of primary benzylic and aliphatic methyl ethers within the molecule (Table 3, entries 12 and 13).

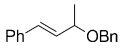
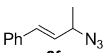
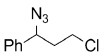
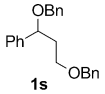
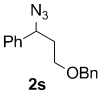
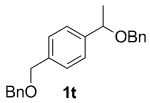
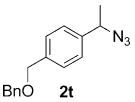
Encouraged by the useful chemoselectivity between the secondary and primary benzyl ethers, we next challenged the site-selective azidation of unsymmetrical dibenzyl ethers, namely



benzyl-protected secondary benzyl alcohols bearing both secondary and primary benzylic moieties (Table 4). Although benzyl ethers are generally deprotected under hydrogenation

Table 4. Chemoselective azidation of unsymmetrical dibenzyl ethers.

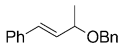
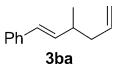
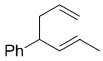
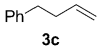
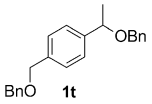
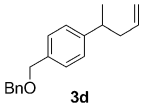
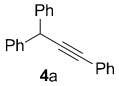
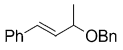
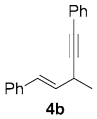
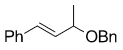
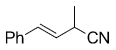
Substrate **1** —($FeCl_3$ (30 mol%), $TMSN_3$ (3 equiv), CH_2Cl_2, RT)→ Product **2**

Entry	Substrate (**1**)	Product (**2**)	Time	Yield [%]
1	 **1o**	 **2b**	1 h	83
2	 **1p**	 **2a**	5 min	97
3	 **1q**	 **2f**	5 min	74
4[a]	 **1r**	 **2h**	4 h	79
5	 **1s**	 **2s**	4 h	64
6	 **1t**	 **2t**	5 min	84

[a] 60 mol% of $FeCl_3$ was used.

Table 5. Direct introduction of carbon nucleophiles.

Substrate **1** —($FeCl_3$ (10 mol%), nucleophile (1.5 equiv), CH_2Cl_2, RT)→ Product **2**

Entry	Substrate	Product	Yield [%] (Time)
nucleophile: allylTMS			
1	 **1a**	 **3a**	92 (1.5 h)
2	 **1p**	 **3a**	91 (2 h)
3	 **1q**	 **3ba** +  **3bb**	59 30 (1 h)
4	 **1k**	 **3c**	trace
5	 **1t**	 **3d**	32 (5 h)[a]
nucleophile: Ph—≡—TMS			
6	 **1a**	 **4a**	54 (30 min)
7	 **1q**	 **4b**	44 (4 h)
nucleophile: TMSCN			
8	 **1a**	 **5a**	48 (7 h) [96 (5 min)][b]
9	 **1q**	 **5ba**	49 (3 h)[c] [78 (1 h)][b,d]

[a] 50% of substrate was recovered; [b] $AuCl_3$ was used instead of $FeCl_3$; [c] 30 mol% of $FeCl_3$ was used; [d] 13% of **5bb** was also obtained.

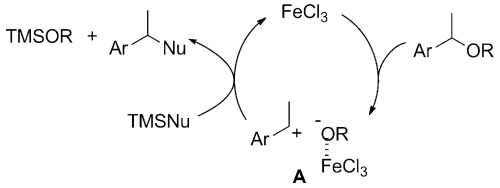

5bb

conditions,[1] selective deprotection (cleavage of the benzyl–oxygen bond) of a specific benzyl ether in a substrate bearing various benzylic positions, such as the substrates shown in Table 4, is difficult. Therefore, a direct and chemoselective conversion method at the desired benzylic position would be a useful tool to construct target molecules. The iron-catalyzed azidation of 1-phenylethanol benzyl ether (**1o**) was chemoselectively performed at only the secondary benzylic position to provide the secondary benzylic azide **2b** in high yield (Table 4, entry 1). Benzyl ethers **1p–r**, derived from benzhydrol, 4-phenyl-3-buten-2-ol, and 1-phenyl-3-chloropentan-1-ol, also efficiently underwent the present azidation to give the corresponding secondary benzylic and allylic azides **2a**, **2f**,[12] and **2h** (Table 4, entries 2–4). Furthermore, the reaction of benzyl ethers **1s** and **1t**, possessing three benzylic positions within the molecule, provided the desired azides **2s** and **2t**, which resulted from chemoselective azidation at the secondary benzylic positions (Table 4, entries 5 and 6).

The present method could be applicable to the $FeCl_3$-catalyzed direct nucleophilic substitutions of secondary benzyl methyl ethers or secondary dibenzyl ethers by using carbon nucleophiles instead of $TMSN_3$ (Table 5). C–C bond formations of benzyl methyl ether **1a** or dibenzyl ether **1p** by using allyl TMS gave the allylated product **3a** in excellent yields (Table 5, entries 1 and 2). The allylation of allylic benzyl ether **1q** provides the corresponding products **3ba** and **3bb** in 59 and 30%, respectively (Table 5, entry 3).[12] The primary benzyl methyl ether **1k** was not applicable to the present allylation,

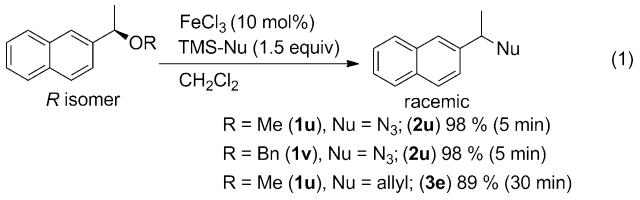
along with the corresponding azidation (Table 5, entry 4). The chemoselective allylation at the secondary position of **1t** could be achieved, even though desired product **3d** was obtained in low yield (32%) and 50% of the starting material (**1t**) was recovered (Table 5, entry 5).[13] The alkynylation and cyanation reactions with TMS phenylacetylene and TMSCN, respectively, also proceeded smoothly to provide the corresponding alkynylated and cyanated products (Table 5, entries 6–9). In particular, the use of $AuCl_3$ as the Lewis acid instead of $FeCl_3$ could strongly promote the cyanation (Table 5, entries 8 and 9).

The iron-catalyzed azidation and allylation of the chiral benzyl methyl ether (**1u**) and dibenzyl ether (**1v**) smoothly proceeded to give the racemic azidated and allylated products in high yields [Eq. (1)], which clearly indicated that the present reaction proceeds via carbocation intermediate **A** (Scheme 2).[14] The oxygen atom on the benzyl methyl ether or



Scheme 2. Proposed mechanism of the reaction.

dibenzyl ether can be effectively activated by the Lewis acidity of $FeCl_3$ to form the thermodynamically more stable secondary benzyl cation intermediate **A**, which smoothly undergoes the nucleophilic addition to give the corresponding product.



Conclusions

In conclusion, we have established a direct and chemoselective functionalization method by using benzyl methyl and unsymmetrical dibenzyl ethers derived from secondary and tertiary benzyl alcohols. These reactions are the first examples for azidation, alkynylation, and cyanation with methoxy and benzyloxy functionalities as leaving groups and were accomplished by the use of the inexpensive and widely utilized $FeCl_3$ as the catalyst. The present method possesses not only a novel chemoselectivity but also the advantage of shortened synthetic steps. It provides a novel synthetic strategy due to the direct process without the deprotection of the methyl and benzyl ethers.

Experimental Section

Azidation (allylation, alkynylation, and cyanation) reactions

Typical procedure: Trimethylsilylazide (0.225 mmol) and $FeCl_3$ or $FeBr_3$ (0.015 mmol; 10 mol% for substrate) were added to a solution of the methyl ether or benzyl ether (0.15 mmol) in CH_2Cl_2 (0.2 M; 0.75 mL) at room temperature under argon. After stirring for the adequate reaction time, the mixture was quenched with water and extracted with CH_2Cl_2. The combined organic layer was dried with Na_2SO_4, and concentrated in vacuo. The residue was purified by column chromatography with hexane/diethyl ether (10/1) as the eluent.

Azidodiphenylmethane (2a): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 7.37–7.29$ (m, 10H), 5.70 ppm (s, 1H).

1-Azido-1-phenylethane (2b): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 7.40–7.36$ (m, 2H), 7.33–7.30 (m, 3H), 4.61 (q, $J = 6.8$ Hz, 1H), 1.53 ppm (d, $J = 6.8$ Hz, 3H).

1-Azido-1-(4-methoxyphenyl)ethane (2c): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.26$ (d, $J = 8.5$ Hz, 2H), 6.91 (d, $J = 8.5$ Hz, 2H), 4.58 (q, $J = 7.0$ Hz, 1H), 3.82 (s, 3H), 1.51 ppm (d, $J = 7.0$ Hz, 3H).

1-Azido-1-(4-chlorophenyl)ethane (2d): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.35$ (d, $J = 8.5$ Hz, 2H), 7.27 (d, $J = 8.5$ Hz, 2H), 4.60 (q, $J = 7.0$ Hz, 1H), 1.51 ppm (d, $J = 7.0$ Hz, 3H).

1-Azidoindan (2e): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta =$ 7.40 (d, $J = 7.0$ Hz, 1H), 7.31–7.26 (m, 3H), 4.87 (dd, $J = 7.5$, 5.0 Hz, 1H), 3.12–3.06 (m, 1H), 2.92–2.86 (m, 1H), 2.49–2.42 (m, 1H), 2.17–2.10 ppm (m, 1H).

(1*E*)-3-Azido-1-phenyl-1-butene (2f): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 7.41–7.39$ (m, 2H), 7.35–7.31 (m, 2H), 7.29–7.25 (m, 1H), 6.60 (d, $J = 16.0$ Hz, 1H), 6.14 (dd, $J = 16.0$, 7.6 Hz, 1H), 4.17 (dq, $J = 6.8$ Hz, 1H), 1.37 ppm (d, $J = 7.2$ Hz, 3H).

3-Azido-1-phenyl-1-butyne (2g): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.46$ (d, $J = 8.0$ Hz, 2H), 7.34–7.30 (m, 3H), 4.41 (q, $J = 7.0$ Hz, 1H), 1.53 ppm (d, $J = 7.0$ Hz, 3H).

(1-Azido-3-chloropropyl)benzene (2h): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.42–7.39$ (m, 2H), 7.37–7.32 (m, 3H), 4.76 (dd, $J = 9.0$, 6.0 Hz, 1H), 3.68–3.63 (m, 1H), 3.51–3.46 (m, 1H), 2.27–2.22 (m, 1H), 2.13 ppm (m, 1H).

(1-Azido-1-methylethyl)benzene (2i): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.45$ (d, $J = 6.5$ Hz, 2H), 7.38 (t, $J = 7.5$ Hz, 2H), 7.29 (t, $J = 7.5$ Hz, 1H), 1.65 ppm (s, 6H).

Azidotriphenylmethane (2j): The ^{1}H NMR spectrum of the product was identical to that given in reference [8]. ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 7.34–7.27$ ppm (m, 15H).

1-Azido-1-(4-(methoxymethyl)phenyl)ethane (2m): Colorless oil; IR (ATR): $\tilde{\nu} = 2927$, 2089, 1452, 1378, 1242, 1098, 1020 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 7.36–7.30$ (m, 4H), 4.62 (q, $J = 7.0$ Hz, 1H), 4.46 (s, 2H), 3.40 (s, 3H), 1.52 ppm (d, $J = 7.0$ Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 140.0$, 137.9, 127.8, 126.2, 74.0, 60.6, 58.0, 21.3 ppm; ESI-HRMS: m/z calcd for $C_{10}H_{13}N_3ONa$ $[M+Na]^+$: 214.0951; found: 214.0986.

1-Azido-3-methoxy-1-phenylpropane (2n): Colorless oil; IR (ATR): $\tilde{\nu}$ = 2925, 2876, 2092, 1454, 1386, 1311, 1243, 1179, 1118, 1071, 1012 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ = 7.40–7.37 (m, 2H), 7.34–7.32 (m, 3H), 4.67 (dd, J = 8.5, 6.0 Hz, 1H), 3.52–3.47 (m, 1H), 3.35–3.31 (m, 1H), 3.34 (s, 3H), 2.08–2.04 (m, 1H), 2.03–1.94 ppm (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 139.5, 128.8, 128.2, 126.9, 68.8, 62.9, 58.7, 36.4 ppm; ESI-HRMS: m/z calcd for $C_{10}H_{13}N_3O$ $[M]^+$: 191.1053; found: 191.1097.

1-Azido-3-benzyloxy-1-phenylpropane(2s): Colorless oil; IR (ATR): $\tilde{\nu}$ = 3031, 2859, 2092, 1494, 1453, 1362, 1244, 1101, 1070, 1027 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ = 7.38–7.29 (m, 10H), 4.71 (dd, J = 8.0, 7.0 Hz, 1H), 4.51 (d, J = 12.0 Hz, 1H), 4.47 (d, J = 12.0 Hz, 1H), 3.61–3.57 (m, 1H), 3.44–3.40 (m, 1H), 2.12–2.06 (m, 1H), 2.03–1.96 ppm (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 140.2, 138.2, 138.1, 128.4, 128.1, 127.8, 127.7, 126.4, 72.2, 71.7, 60.8, 21.6 ppm; ESI-HRMS: m/z calcd for $C_{16}H_{17}N_3ONa$ $[M+Na]^+$: 290.1264; found: 290.1256.

1-Azido-1-(4-(benzyloxymethyl)phenyl)ethane (2t): Colorless oil; IR (ATR): $\tilde{\nu}$ = 2927, 2855, 2090, 1496, 1453, 1421, 1376, 1359, 1304, 1242, 1088, 1071, 1019 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ = 7.40–7.29 (m, 9H), 4.62 (q, J = 7.0 Hz, 1H), 4.57 (s, 2H), 4.56 (s, 2H), 1.52 ppm (d, J = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ = 139.5, 138.2, 128.8, 128.4, 128.2, 127.7, 127.6, 126.9, 73.1, 66.5, 63.1, 36.5 ppm; ESI-HRMS: m/z calcd for $C_{16}H_{17}N_3ONa$ $[M+Na]^+$: 290.1264; found: 290.1264.

2-(1-Azidoethyl)naphthalene (2u): The ^1H NMR spectrum of the product was identical to that given in reference [8]. ^1H NMR (500 MHz, $CDCl_3$): δ = 7.88–7.84 (m, 3H), 7.83 (s, 1H), 7.77–7.48 (m, 2H), 7.45 (dd, J = 7.0, 1.5 Hz, 1H), 4.79 (q, J = 7.0 Hz, 1H), 1.61 ppm (d, J = 7.0 Hz, 3H).

4,4-Diphenylbut-1-ene (3a): The ^1H NMR spectrum of the product was identical to that given in reference [15]. ^1H NMR (500 MHz, $CDCl_3$): δ = 7.30–7.24 (m, 8H), 7.20–7.17 (m, 2H), 5.77–5.69 (m, 1H), 5.04 (d, J = 16.5 Hz, 1H), 4.96 (d, J = 10.0 Hz, 1H), 4.02 (t, J = 7.0 Hz, 1H), 2.83 ppm (t, J = 7.0 Hz, 2H).

3-Methyl-1-phenylhexa-1,5-diene and 4-phenylhepta-1,5-diene (3ba and 3bb): An approximately 2:1 mixture of inseparable **3ba** and **3bb** was obtained. Colorless oil; IR (ATR): $\tilde{\nu}$ = 3077, 3026, 2960, 2924, 1640, 1600, 1493, 1450, 1376, 1102, 1072, 1029 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ = 7.42–7.23 (m, 5H), 6.41 (d, J = 16.0 Hz, 0.67H), 6.21 (dd, J = 16.0, 7.6 Hz, 0.67H), 5.92–5.82 (m, 0.67H), 5.80–5.72 (m, 0.33H), 5.68–5.62 (m, 0.33H), 5.54–5.47 (m, 0.33H), 5.12–4.99 (m, 2H), 3.35 (q, J = 7.2 Hz, 0.33H), 2.52–2.42 (m, 1.33H), 2.30–2.14 (m, 1.34H), 1.72 (d, J = 6.4 Hz, 1H), 1.15 ppm (d, J = 6.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 144.7, 137.8, 137.0, 136.0, 134.4, 128.4, 128.3, 128.2, 127.6, 126.8, 126.0, 125.9, 116.0, 115.8, 48.8, 41.4, 40.4, 36.9, 19.9, 17.9 ppm; ESI-HRMS: m/z calcd for $C_{16}H_{17}N_3ONa$ $[M+Na]^+$: 195.1144; found: 195.1139.

4-(4-(Benzyloxymethyl)phenyl)pent-1-ene (3d): Colorless oil; IR (ATR): $\tilde{\nu}$ = 3028, 2960, 2924, 2855, 1639, 1513, 1495, 1453, 1419, 1359, 1260, 1209, 1091, 1073, 1027 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–7.29 (m, 7H), 7.18 (d, J = 7.6 Hz, 2H), 5.74–5.67 (m, 1H), 5.02–4.93 (m, 2H), 4.56 (s, 2H), 4.53 (s, 2H), 2.79 (q, J = 6.8 Hz, 1H), 2.40–2.34 (m, 1H), 2.31–2.26 (m, 1H), 1.24 ppm (d, J = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 147.3, 146.5, 138.4, 137.1, 128.4, 127.9, 127.8, 127.6, 127.0, 115.9, 72.1, 72.0, 42.6, 39.5, 21.5 ppm; ESI-HRMS: m/z calcd for $C_{16}H_{17}N_3ONa$ $[M+Na]^+$: 289.1563; found: 289.1560.

4-Naphthylpent-1-ene (3e): The ^1H NMR spectrum of the product was identical to that given in reference [2a]. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.80–7.77 (m, 3H), 7.61 (s, 1H), 7.46–7.39 (m, 2H), 7.35 (d, J = 8.4 Hz, 1H), 5.79–5.68 (m, 1H), 5.03–4.94 (m, 2H), 2.98–2.93 (m, 1H), 2.52–2.45 (m, 1H), 2.41–2.33 (m, 1H), 1.34 ppm (d, J = 6.8 Hz, 3H).

1,3,3-Triphenyl-1-propyne (4a): The ^1H NMR spectrum of the product was identical to that given in reference [16]. ^1H NMR (500 MHz, $CDCl_3$): δ = 7.49–7.44 (m, 6H), 7.34–7.30 (m, 9H), 5.21 ppm (s, 1H).

(*E*)-(3-Methylpent-1-en-4-yne-1,5-diyl)dibenzene (4b): The ^1H NMR spectrum of the product was identical to that given in reference [17]. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.45 (d, J = 7.2 Hz, 2H), 7.39 (d, J = 7.6 Hz, 2H), 7.34–7.29 (m, 5H), 7.23 (d, J = 8.8 Hz, 1H), 6.68 (d, J = 7.6 Hz, 1H), 6.24 (dd, J = 7.6, 6.0 Hz, 1H), 3.57–3.53 (m, 1H), 1.45 ppm (d, J = 6.0, 3H).

2,2-Diphenylacetonitrile (5a): The ^1H NMR spectrum of the product was identical to that given in reference [18]. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–7.30 (m, 10H), 5.13 ppm (s, 1H).

(*E*)-2-Methyl-4-phenyl-3-butenenitrile (5ba): The ^1H NMR spectrum of the product was identical to that given in reference [19]. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.40–7.26 (m, 5H), 6.73 (d, J = 16.0 Hz, 1H), 6.07 (dd, J = 16.0, 6.0 Hz, 1H), 3.55–3.47 (m, 1H), 1.52 ppm (d, J = 7.2 Hz, 3H).

(*E*)-4-Methyl-2-phenyl-3-butenenitrile (5bb): Yellow oil; IR (ATR): $\tilde{\nu}$ = 3031, 2919, 2241, 1600, 1493, 1452, 1379, 1075, 1029 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ = 7.41–7.37 (m, 2H), 7.34–7.31 (m, 3H), 5.96–5.88 (m, 1H), 5.53 (dd, J = 15.2, 6.4 Hz, 1H), 4.48 (d, J = 6.4 Hz, 1H), 1.76 ppm (d, J = 6.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 135.0, 129.8, 129.1, 128.1, 127.4, 125.2, 119.2, 39.8, 17.6 ppm; ESI-HRMS: m/z calcd for $C_{16}H_{17}N_3ONa$ $[M+Na]^+$: 180.0784; found: 180.0782

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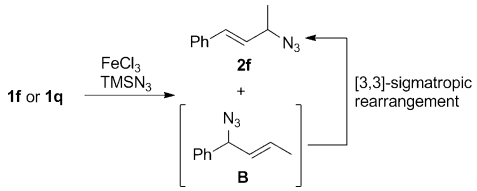

[13] Although 10 mol% of $FeCl_3$ catalyzed no allylation of the primary benzyl methyl ether (**1k**), a complex mixture was obtained by the use of 30 mol% of $FeCl_3$. Therefore, the catalyst loading of $FeCl_3$ could not be increased to consume the starting material in the case of the chemoselective allylation with **1t**. It seems to be difficult to accomplish the chemoselective C–C bond formations with distinction between the secondary and primary benzyl ethers by the use of allyl TMS, TMS phenylacetylene, and TMSCN as carbon nucleophiles.

[14] The addition of one equivalent of tetracyanoethylene (TCNE) as a single-electron scavenger into the reaction mixture did not influence the reaction efficiency. Therefore, the present reaction proceeds via the carbocation intermediate, not the radical pathway. The result of the reaction with TCNE is depicted in the Supporting Information.

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