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Undesirable deprotection of *O*-TBDMS groups by Pd/C-catalyzed hydrogenation and chemoselective hydrogenation using a Pd/C(en) catalyst

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Abstract—In general, *O*-TBDMS protective groups have been believed to be stable toward Pd/C-catalyzed hydrogenation conditions. In practice, however, frequent and unexpected loss of the TBDMS protective group of a variety of hydroxyl functions occurred under neutral and mild hydrogenation conditions using 10% Pd/C in MeOH. When a 10% Pd/C–ethylenediamine complex catalyst [10% Pd/C(en)] was used instead of 10% Pd/C, the undesirable problem was perfectly overcome and the chemoselective hydrogenation of reducible functionalities leaving intact the TBDMS protective group was achieved. © 2001 Elsevier Science Ltd. All rights reserved.

Since a hydroxyl group can participate in numerous transformations under mild conditions, a central problem in organic synthesis is to ensure that a specific hydroxyl function in a multifunctional molecule is protected from unwanted reactions altogether or until such time as its intrinsic reactivity is required. Protective groups suitable for contemporary synthesis should ensure efficiency of preparation, selective removal and stability under the intended reaction conditions. Silyl-protective groups have been and are widely used among organic chemists especially in multi-step natural product synthesis. An especially important requirement of the protective groups is to have sets of orthogonally usable groups available, which can be introduced and removed in essentially quantitative yields. Since the introduction of a *tert*-butyldimethylsilyl (TBDMS) group to synthetic chemistry by Corey,[1] the TBDMS ether has become among the most frequently used silyl protective groups for a hydroxyl function. It is well known that the TBDMS ether is remarkably more stable to a variety of organic reaction conditions than the trimethylsilyl (TMS) ethers.[2] Although it has been common knowledge that the TBDMS ether is inert towards palladium-catalyzed hydrogenation conditions,[1] we have frequently observed that it can be completely or partially hydrogenolyzed to form the parent alcohols (e.g. using 10% Pd/C, 1 atm H_2, MeOH solvent, at 20°C).[3] The unexpected loss of the TBDMS protective group from a hydroxyl function would cause extensive damage to a synthetic process. Further, Cormier et al. have reported the removal of the TBDMS protective group from primary and secondary hydroxyl groups by catalytic transfer hydrogenolysis (CTH) using PdO as a catalyst in refluxing cyclohexene–MeOH.[4] Therefore, we questioned whether the TBDMS group is essentially stable under palladium-catalyzed hydrogenation conditions. Herein we provide a detailed discussion regarding the stability of the TBDMS ether under hydrogenation conditions using Pd catalysts and further, disclose a very practical catalyst that overcomes the undesirable problem.

1. Results and discussion

In our initial investigations, the stability of the TBDMS group of cinnamyl alcohol TBDMS ether (**1a**)[5] under hydrogenation conditions using several Pd catalysts was studied (Table 1). All the reactions were carried out on a 0.25 mmol scale in MeOH (1 mL) under hydrogen atmosphere (1 atm) at room temperature for 24 h. When 2 mol% of Pd black as a catalyst was used, 73% of the TBDMS protective group was deprotected (entry 1). Moreover, when 5% Pd/C or 10% Pd/C (10% of the weight of the substrate) purchased from Aldrich was used, the TBDMS protective group was surprisingly and completely deprotected to give 3-phenyl-1-propanol (**3a**) as the sole product (entries 2 and 3). To eliminate the possibility of the methanolysis by a contaminated acid in Pd/C-catalyzed cleavage of the TBDMS protective group, the reaction of **1a** was performed without the hydrogen condition. As a consequence of the reaction, neither desilylation nor hydrogenation occurred, even after 24 h (entry 4). Further, by use of freshly prepared absolute hexane[6] as a non-protic solvent, partial but appreciable cleavage of the TBDMS group of **1a** was observed (entry 5).

Keywords: TBDMS ethers; desilylation; Pd/C; Pd/C(en); chemoselective hydrogenation.

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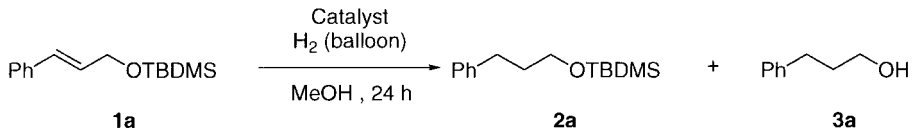
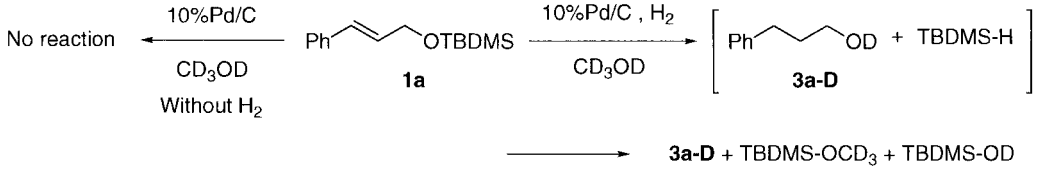
Table 1. Hydrogenation of **1a** using various Pd catalysts



1a **2a** **3a**

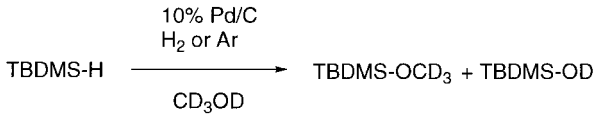
Entry	Catalyst	Product (%)[a]	
		2a	**3a**
1	Pd black[b]	27	73
2	5% Pd/C[c]	0	100
3	10% Pd/C[c]	0	100
4	(Without H_2)	No reaction	No reaction
5	(In hexane instead of MeOH)	86	14
6	(With NH_3)[d]	100	0
7	10% Pd/C(en)	100	0

Unless otherwise specified, the reaction was carried out using 0.25 mmol of **1a** with catalyst (10% of the weight of the substrate) in MeOH (1 mL) under hydrogen atmosphere (1 atm) at room temperature for 24 h.
[a] Determined by ^{1}H NMR.
[b] 2 mol% of Pd.
[c] Purchased from Aldrich.
[d] Ammonia–methanol (0.5 equiv. of NH_3) was added to the reaction mixture.



Scheme 1.

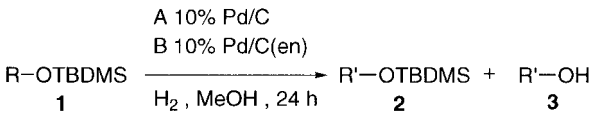
When using CD_3OD as a solvent for the 10% Pd/C-catalyzed hydrogenation of **1a**, quantitative formation of TBDMS-OCD_3 and TBDMS-OD was observed by ^{13}C NMR together with the desilylated alcohol (**3a**–**D**) (Scheme 1). No reaction (solvolysis) was observed, as well as when MeOH was used as a solvent (Table 1, entry 4), even after 24 h without hydrogen conditions. Although *tert*-butyldimethylsilane (TBDMS-H) has not been detected, probably owing to its instability in the presence of 10% Pd/C in CD_3OD,[7] TBDMS-OCD_3 and TBDMS-OD were formed by the 10% Pd/C-catalyzed solvolysis of TBDMS-H with CD_3OD and contaminated water in commercial CD_3OD (Scheme 1). The theory was further tested by the 10% Pd/C-catalyzed solvolysis using a commercial TBDMS-H in CD_3OD under hydrogen or Ar atmosphere. Although TBDMS-H was stable without 10% Pd/C in CD_3OD at least during the ^{13}C NMR operation period, the result showed that the formation of the same solvolysis products, TBDMS-OCD_3 and TBDMS-OD, was observed within only 0.5 h by ^{13}C NMR as expected (Scheme 2). This provides evidence that TBDMS-H is a key product in this reaction and suggests that the 10% Pd/C-catalyzed solvolysis of TBDMS-H with MeOH (CD_3OD) and water (D_2O or DHO) must proceed subsequently. Therefore, it was clearly suggested that the deprotection of the TBDMS group proceeded through hydrogenolysis catalyzed by palladium.

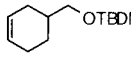
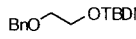
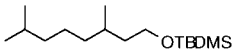
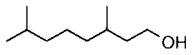
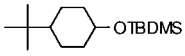
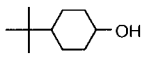
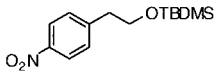
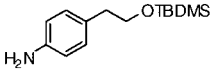
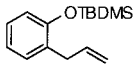
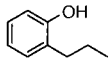
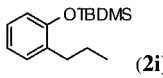


Scheme 2.

We have recently demonstrated the addition of a catalytic amount of nitrogen containing a base, such as ammonia, pyridine, ammonium acetate and so on, to the reaction system selectively suppressed the Pd/C-catalyzed hydrogenolysis of the O-benzyl protective group of alcohols in the coexistence of other reducible functionalities (e.g. olefin, N-Cbz, nitro, benzyl ester or azide).[8] We expected that the undesirable deprotection of the TBDMS group was also suppressed by the addition of a catalytic amount of a nitrogen-containing base if the TBDMS group was actually hydrogenolyzed by palladium. In fact, the desilylation of the TBDMS group was thoroughly suppressed, and chemoselective hydrogenation of olefin was achieved in the presence of 0.5 equiv. vs **1a** of ammonia to give **2a** as the sole product (entry 6). Furthermore, we have recently reported a couple of chemo- and regio-selective hydrogenation methods using a carbon-supported Pd–ethylenediamine complex [Pd/C(en)][9] that possesses less catalytic activity toward benzyl ethers,[9a] N–Z protective groups,[9b] benzyl alcohols,[9c] and epoxides[9d] compared to commercial Pd/C because the coordinated ethylenediamine acts as a gentle catalyst-poison. We expected that employment of 10% Pd/C(en)[10] instead of 10% Pd/C for the hydrogenation of the TBDMS ethers would inhibit deprotection of the TBDMS group. As the result, the hydrogenation of **1a** using 10% Pd/C(en) led to the chemoselective hydrogenation of only the olefin function (entry 7).

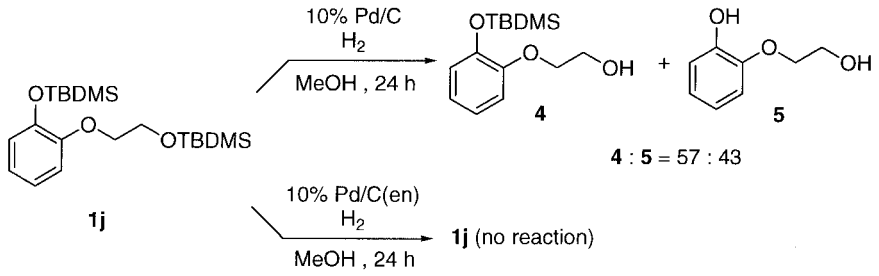
Table 2. Hydrogenation in the presence of *O*-TBDMS group using 10% Pd/C or 10% Pd/C(en) as a catalyst; 10% Pd/C was purchased from Aldrich and 10% Pd/C(en) was prepared from 10% Pd/C (Aldrich)[9]



Entry	Substrate (**1** or **2a**)	Catalyst	Ratio of *O*-TBDMS cleavage (%)[a]	Product	Yield (%)[b]
1	**1a**[5] PhCH=CHCH$_2$OTBDMS	A	100	PhCH$_2$CH$_2$CH$_2$OH (**3a**)[c]	88
2		B	0	PhCH$_2$CH$_2$CH$_2$OTBDMS (**2a**)	93
3	**2a**[15] PhCH$_2$CH$_2$CH$_2$OTBDMS	A	100	PhCH$_2$CH$_2$CH$_2$OH (**3a**)[c]	97
4		B	0	Recovery (**2a**)	100
5	**1b**[11] CH$_2$=CH(CH$_2$)$_8$OTBDMS	A	100	C$_{10}$H$_{21}$OH (**3b**)[c]	80
6		B	0	C$_{10}$H$_{21}$OTBDMS (**2b**)[7]	100
7	**1c** 	A	100	CyCH$_2$OH (**3c**)[c]	74
8		B	0	CyCH$_2$OTBDMS (**2c**)	92
9	**1d**[13] 	A	100	HOCH$_2$CH$_2$OH (**3d**)[c]	73
10		B	0	Recovery (**1d**)	100
11	**1e** 	A	41	**1e** +  (**3e**)[c]	-
12		B	0	Recovery (**1e**)	99
13	**1f**[15] *O*-TBDMS-Cholesterol	A	44	**1f** + Cholesterol (**3f**)[c]	-
14		B	0	Recovery (**1f**)	93
15	**1g**[16] 	A	31	**1g** +  (**3g**)[c]	-
16		B	0	Recovery (**1g**)	99
17	**1h** 	A	0	 (**2h**)	96
18		B			99
19	**1i**[12] 	A	8	**2i** +  (**3i**)[c]	-
20		B	0	 (**2i**)	98

[a] Determined by ^{1}H NMR.
[b] Isolated yield.
[c] Commercially available (Aldrich or TCI).
Unless otherwise specified, the reaction was carried out using 0.25 mmol of the substrate (**1a–i** and **2a**) with catalyst (10% of the weight of the substrate) in MeOH (1 mL) under hydrogen atmosphere (1 atm) at room temperature for 24 h.

To explore the generality of the undesirable hydrogenolysis of the TBDMS ether with commercial 10% Pd/C and the scope of the chemoselective hydrogenation with 10% Pd/C(en) catalyst, the hydrogenation of various substrates was investigated (Table 2). The results shown in entries 1, 2, 5–8, 17–20 demonstrate that the hydrogenation of readily reducible (less steric hindrance) olefin (**1a**, **1b**,[11] **1c** and **1i**[12]) and nitro (**1h**) functionalities can be successfully carried out using either 10% Pd/C or 10% Pd/C(en) as a catalyst. Although the hydrogenolytic debenzylation of **1d**[13] using commercial 10% Pd/C, of course, proceeded smoothly (entry 9), the hydrogenation using 10% Pd/C(en) completely tolerates the benzyl ether of **1d** (entry 10) as already reported by us.[9a] The tri-substituted olefin function of **1f**[14] was stable under these conditions using either 10% Pd/C or 10% Pd/C(en) (entries 13 and 14). On the other hand, we made the unexpected and extremely serious observation that the TBDMS protective group of primary alcohols (**1a–d** and **2a**[15]) can be hydrogenolyzed easily using commercial 10% Pd/C as a catalyst to form the parent alcohols as the sole product, respectively (entries 1, 3, 5, 7 and 9). The TBDMS ether of **1e**, **1f** or **1g**[16] was partially



Scheme 3.

hydrogenolyzed (41, 44 or 31%, respectively) under these conditions to give a mixture of **1e** and **3e**, or **1f** and **3f** or **1g** and **3g** (entries 11, 13 and 15). It should be noted that the hydrogenolysis tolerates the TBDMS ethers possessing an amino moiety within a molecule of the product due to the catalyst-poisonous effect (**2h**, entry 17 and see also Table 1, entry 6). An aryl TBDMS ether (**1i**) seems to be more stable than an alkyl TBDMS (only 8% of the *O*-TBDMS cleaved, entry 19, see also Scheme 1).[17] On the other hand, when the 10% Pd/C(en) was used as a catalyst, no competitive and reluctant hydrogenolysis of the TBDMS ether was observed, without exception, under the same conditions (entries 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20) and chemoselective hydrogenation proceeded perfectly (entries 2, 6, 8, 18 and 20).

Furthermore, the competitive reaction of bis-TBDMS ether (**1j**) possessing an alkyl TBDMS ether and an aryl TBDMS ether was also examined. Although complete desilylation of the alkyl TBDMS ether and partial desilylation of the aryl TBDMS ether proceeded with commercial 10 % Pd/C (**4**:**5**=57:43), no hydrogenolysis of either the alkyl or aryl TBDMS ether occurred when 10% Pd/C(en) was used as a catalyst (Scheme 3).

2. Conclusions

We have clearly demonstrated the unreliability of the TBDMS protective group for hydroxyl functions, especially primary alcohols, under the hydrogenation conditions using 10% Pd/C catalyst. We believe that deprotection of the TBDMS group proceeded through hydrogenolysis catalyzed by palladium on carbon. Moreover, we have found the use of the 10% Pd/C(en) catalyst totally suppressed the hydrogenolysis of the TBDMS ether and have developed a reliable and chemoselective hydrogenation method of reducible functionalities (e.g. olefin or nitro group) in the presence of the TBDMS ether. The simplicity of this method makes it an attractive new and safe tool for the organic chemist.

3. Experimental

All reagents were purchased from commercial suppliers and used without further purification. 10% Pd/C was purchased from Aldrich. 10% Pd/C(en) was prepared from 10% Pd/C purchased from Aldrich according to the previously published procedure.[9a] Flash column chromatography was performed with Merck silica gel 60 (230–400 mesh) under air pressure (max 1 atm). All reactions were monitored by thin-layer chromatography (TLC) performed on glass-backed silica gel 60 F_{254}, 0.2 mm plates (Merck), and compounds were visualized under UV light (254 nm) or *p*-anisaldehyde solution with subsequent heating. ^{1}H and ^{13}C NMR spectra were obtained with a JEOL GX-270 (^{1}H, 270 MHz) or a JEOL EX-400 (^{1}H, 400 MHz, and ^{13}C, 100 MHz) spectrometer. Chemical shifts are given in parts per million from Me_4Si in $CDCl_3$ and coupling constants (*J*) were reported in hertz (Hz). Low- and high-resolution mass spectra were taken on a JEOL JMS-SX 102A machine. Microanalyses were accomplished at the Microanalytical Laboratory of Gifu Pharmaceutical University, Japan. All TBDMS ethers were prepared according to the standard procedure.[18]

3.1. Hydrogenation of 1a using Pd catalysts (Table 1)

After two vacuum/H_2 cycles to remove air from the reaction tube, a stirred mixture of the substrate (**1a**)[5] (0.25 mmol), catalyst Pd black (2 mol%), 5% Pd/C, 10% Pd/C or 10% Pd/C(en) (10% of the weight of the substrate for Pd/Cs) in MeOH or absolute hexane (1 mL) was hydrogenated at ambient pressure (balloon) and temperature (ca. 20°C) for 24 h. In the case of entry 4, the reaction was performed without hydrogen. In the case of entry 6, 0.5 equiv. of 2 M ammonia–methanol was added to the reaction mixture. The reaction mixture was filtered using a celite cake or a membrane filter (Advantec Dismic-13HP, 0.45 μm) and the filtrate was concentrated in vacuo. The quantitative conversion of the substrate and the products ratio of **2a**[15] and **3a** were confirmed by ^{1}H NMR of the crude mixture in $CDCl_3$.

3.2. Hydrogenation of 1a in CD_3OD (Scheme 1)

A stirred mixture of **1a** (15 mg, 0.06 mmol), 10% Pd/C (1.5 mg) in CD_3OD (0.5 mL) was hydrogenated at ambient pressure (balloon) and temperature (ca. 20°C) for 24 h. To determine volatile compounds, the reactions were performed in an NMR tube. The formation of cinnamyl alcohol-d_1 (**3a**–**D**), *tert*-butyldimetylsilyl methyl-d_3 ether (TBDMS-OCD_3)[19] and *tert*-butyldimethylsilanol-d_1 (TBDMS-OD) were confirmed by ^{13}C NMR of the reaction mixture.

3.3. Pd-catalyzed solvolysis of *tert*-butyldimethylsilane[7] (Scheme 2)

A stirred mixture of *tert*-butyldimethylsilane (TBDMS-H) (15 mg, 0.13 mmol), 10% Pd/C (1.5 mg) in CD_3OD (0.5 mL) was stirred at ambient pressure (H_2 or Ar balloon)

and temperature (ca. 20°C) for 0.5 h. To determine volatile compounds, the reactions were performed in an NMR tube. The formation of *tert*-butyldimetylsilyl methyl-d_3 ether (TBDMS-OCD_3) and *tert*-butyldimethylsilanol-d_1 (TBDMS-OD) was confirmed by ^{13}C NMR of the reaction mixture.

3.3.1. 1-*tert*-Butyldimethylsilyloxymethyl-3-cyclohexene (1c). To a solution of 3-cyclohexene-1-MeOH (1.12 g, 10.00 mmol), *tert*-butylchlorodimethylsilane (1.66 g, 11.00 mmol) and 4-dimethylaminopyridine (48 mg, 0.40 mmol) in CH_2Cl_2 (20 mL) was added triethylamine (1.70 mL, 12.00 mmol). The reaction mixture was stirred at room temperature for 24 h. The solvent was evaporated and the residue was partitioned between ether (30 mL) and water (30 mL). The organic layer was washed with water (30 mL) and brine (30 mL) and dried over anhydrous sodium sulfate. The solvent was removed in vacuo, and flash column chromatography (hexane) yielded **1c** (1.49 g, 66%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 0.07 (s, 6H), 0.92 (s, 9H), 1.26–1.28 (m, 1H), 1.61–1.82 (m, 3H), 2.10–2.14 (m, 3H), 3.49–3.54 (m, 2H), 5.67–5.72 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.3, 18.4, 24.8, 25.3, 26.0, 28.2, 36.4, 68.0, 126.3, 127.1; MS (FAB, NBA) *m/z* (%) 227 (26) [M^++H]; Anal. Calcd for $C_{13}H_{26}OSi$ 1/6H_2O: C, 68.05; H, 11.57. Found: C, 68.05; H, 11.54.

3.3.2. 1-*tert*-Butyldimethylsilyloxy-3,7-dimethyloctane (1e). A colorless oil; ^1H NMR (400 MHz) δ 0.05 (s, 6H), 0.86 (s, 9H), 0.87 (s, 3H), 0.89 (s, 9H), 1.08–1.57 (m, 10H), 3.60–3.67 (m, 2H); ^{13}C NMR δ −5.3, 18.4, 19.8, 22.6, 22.7, 24.7, 26.0, 28.0, 29.5, 37.4, 39.3, 40.0, 61.6; MS (FAB, NBA) *m/z* (%) 237 (13) [M^++H]; Anal. Calcd for $C_{16}H_{36}$Osi 1/8H_2O: C, 69.93; H, 13.30. Found: C, 69.90; H, 13.54.

3.3.3. 1-*tert*-Butyldimethylsilyloxy-2-(4-nitrophenyl)-ethane (1h). A pale yellow oil; ^1H NMR (400 MHz) δ −0.04 (s, 6H), 0.85 (s, 9H), 2.91 (t, *J*=6.4 Hz, 2H), 3.85 (t, *J*=6.4 Hz, 2H), 7.37 (d, *J*=8.8 Hz, 2H), 8.15 (d, *J*=8.8 Hz, 2H); ^{13}C NMR δ −5.5, 18.2, 25.8, 39.2, 63.3, 123.3, 130.0, 146.6, 147.6; HRMS (FAB, NBA) Calcd for $C_{14}H_{24}NO_3Si$ (M^++H) 282.1525. Found 282.1513.

3.3.4. 2-*tert*-Butyldimethylsilyloxy(2-*tert*-butyldimethylsilyloxyethoxy)benzene (1j). A pale yellow oil; ^1H NMR (400 MHz) δ 0.08 (s, 6H), 0.16 (s, 6H), 0.91 (s, 9H), 1.00 (s, 9H), 3.97 (t, *J*=5.5 Hz, 2H), 4.03 (t, *J*=5.5 Hz, 2H), 6.81–6.88 (m, 4H); ^{13}C NMR δ −5.4, −4.6, 18.3, 18.4, 25.8, 25.9, 61.8, 69.9, 113.8, 121.1, 121.2, 121.7, 145.3, 150.4; MS (FAB, NBA) *m/z* (%) 383 (20) [M^++H]; Anal. Calcd for $C_{20}H_{38}O_3Si_2$: C, 62.77; H, 10.01. Found: C, 62.42; H, 10.20.

3.4. General procedure for hydrogenation (Table 2 and Scheme 3)

Unless otherwise specified, the reaction was carried out as follows. After two vacuum/H_2 cycles to remove air from the reaction tube, a stirred mixture of the substrate (**1**) (0.25 mmol), 10% Pd/C or 10% Pd/C(en) (10% of the weight of the substrate) in MeOH (1 mL) was hydrogenated at ambient pressure (balloon) and temperature (ca. 20°C) for 24 h. The reaction mixture was filtered using a celite cake or a membrane filter (Advantec Dismic-13HP, 0.45 μm) and the filtrate was concentrated in vacuo. The quantitative conversion of the substrate and the products ratio of **2** and **3** were confirmed by ^1H NMR of the crude mixture in $CDCl_3$. The crude mixture was purified by flash silica gel column chromatography, if necessary. The products, 3-phenylpropanol (**3a**), decanol (**3b**), cyclohexylmethanol (**3c**), ethyleneglycol (**3d**), 3,7-dimethyl-1-octanol (**3e**), cholesterol (**3f**), 4-*tert*-butylcyclohexanol (**3g**), 2-propylphenol (**3i**) and 2-(2-hydroxyethoxy)phenol (**5**) agreed with the analytical data of commercially available samples.

3.4.1. 1-*tert*-Butyldimethylsilyloxymethylcyclohexane (2c). A colorless oil; ^1H NMR (270 MHz) δ 0.03 (s, 6H), 0.89 (s, 9H), 1.10–1.78 (m, 11H), 3.38 (d, *J*=6.3 Hz, 2H); ^{13}C NMR δ −5.3, 18.4, 26.0, 26.8, 29.8, 40.5, 68.9; HRMS (EI) Calcd for $C_{13}H_{28}NOSi$ (M^+) 228.1909. Found 228.1901.

3.4.2. 1-*tert*-Butyldimethylsilyloxy-2-(4-aminophenyl)-ethane (2h). A brown oil; ^1H NMR (400 MHz) δ 0.00 (s, 6H), 0.88 (s, 9H), 2.71 (t, *J*=6.4 Hz, 2H), 3.49 (brs, 2H), 3.74 (t, *J*=7.3 Hz, 2H), 6.62 (d, *J*=8.3 Hz, 2H), 6.99 (d, *J*=8.3 Hz, 2H); ^{13}C NMR δ −5.4, 18.3, 25.9, 38.8, 64.9, 115.1, 129.1, 129.9, 144.5; HRMS (EI) Calcd for $C_{14}H_{25}NOSi$ (M^+) 251.1705. Found 251.1698.

3.4.3. 1-*tert*-Butyldimethylsilyloxy-2-propylbenzene (2i). A colorless oil, ^1H NMR (400 MHz) δ 0.23 (s, 6H), 0.94 (t, *J*=7.5 Hz, 3H), 1.02 (s, 9H), 1.58 (hex, *J*=7.5 Hz, 2H), 2.55 (t, *J*=7.5 Hz, 2H), 6.77 (d, *J*=7.6 Hz, 1H), 6.87 (t, *J*=7.6 Hz, 1H), 7.05 (t, *J*=7.6 Hz, 1H), 7.12 (d, *J*=7.6 Hz, 1H); ^{13}C NMR δ −4.2, 14.1, 18.2, 23.3, 25.8, 32.7, 118.3, 120.9, 126.5, 130.2, 133.3, 153.5; MS (EI) *m/z* (%) 250 (36) [M^++H], 193 (100), 163 (65); Anal. Calcd for $C_{15}H_{26}OSi$: C, 71.93; H, 10.46. Found: C, 71.68; H, 10.60.

3.4.4. 2-*tert*-Butyldimethylsilyloxy(2-hydroxyethoxy)-benzene (4). A colorless oil; ^1H NMR (400 MHz) δ 0.18 (s, 6H), 1.02 (s, 9H), 2.25 (t, *J*=5.2 Hz, 1H), 3.92 (q, *J*=5.2 Hz, 2H), 4.09 (t, *J*=5.2 Hz, 2H), 6.86–6.92 (m, 4H); ^{13}C NMR δ −4.7, 18.3, 25.6, 61.3, 70.4, 114.6, 121.1, 121.7, 121.9, 145.3, 150.0; HRMS (FAB, NBA) Calcd for $C_{14}H_{24}O_3Si$ (M^++H) 269.1573. Found 269.1566.

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