Deoxygenation of Aliphatic Alcohols via Reduction of New Thioxocarbamate Derivatives

Makoto Oba, Kozaburo Nishiyama*

Department of Material Science and Technology, Tokai University, 317, Nishino, Numazu, Shizuoka 410-03, Japan

Received 6 September 1993; revised 2 December 1993

N-Acylthioxocarbamates, obtained by the reaction of alcohols with acyl isothiocyanates, were reduced by tributylstannane or triphenylsilane under radical conditions to give deoxygenated products of the corresponding alcohols in good yields. An application to regioselective deuteration using tributyldeuteriostannane is also examined.

Deoxygenation of primary and secondary alcohols plays an important role in organic synthesis. Most of the methods available for deoxygenation of sensitive polyfunctionalized molecules are based on radical chemistry,[1] since replacement of a hydroxyl group by hydrogen without rearrangement and elimination, which often occurs in ionic reactions, is significant for stereo- and regioselective deuteration in organic synthesis. Many radical deoxygenation reactions as described above were accomplished by the reduction of thiocarbonyl derivatives of the corresponding alcohols.[2] Among the derivatizing reagents, phenyl chlorothioxocarbonate[3] and diimidazolyl thioketone[4] are well known to be applicable to a wide variety of hydroxy compounds. However these reagents are relatively expensive or unstable to moisture. More recently we reported a new type of deoxygenation reaction of alcohols,[5] in which ethyl, phenyl, and trimethylsilylmethyl isothiocyanates were used for conversion of the alcohols to their thiocarbonyl derivatives. For the addition reaction of the alcohols to isothiocyanates, however, highly toxic bis(tributyltin)oxide should be used as an activator, because these isothiocyanates are generally unreactive toward alcohols under neutral conditions. In this paper, we describe the application of highly reactive electron-deficient isothiocyanates, such as acyl isothiocyanates, as a derivatizing reagent for alcohols without any activator under neutral conditions, and a reduction of derived *N*-acylthioxocarbamate **1** with tributylstannane/azobisisobutyronitrile (AIBN) or the triphenylsilane/triethylborane (Et_3B) system. The procedure using tributyldeuteriostannane provided a convenient method for the regiospecific deoxydeuteration of primary and secondary alcohols without any rearrangements.

Initially, we established a convenient one-pot synthesis of *N*-acylthioxocarbamate **1** by addition of alcohol with acyl isothiocyanate, which was generated from the reaction of acyl chloride and potassium thiocyanate.[6] Thus, a mixture of acetyl chloride and potassium thiocyanate in acetone was stirred at room temperature for 10 minutes, followed by an addition of 2-dodecanol, and then the mixture was refluxed overnight. The desired 2-dodecyl *N*-acetylthioxocarbamate (**1b**) was isolated by flash chromatography on silica gel (eluted by hexane/EtOAc = 9:1) in 63% yield.

Isothiocyanates having other acyl groups such as benzoyl, substituted benzoyl, methoxycarbonyl, and *N,N*-dimethylcarbamoyl, were examined. All derived acyl isothiocyanates were proved to be also reactive toward 2-dodecanol to give the corresponding 2-dodecyl *N*-acylthioxocarbamates **1** in good yields. However these adducts, apart from the methoxycarbonyl and 4-methoxybenzoyl derivatives (**1h** and **1i**), were unsuitable for the subsequent deoxygenation reaction (*vide infra*).

Other alcohols were treated similarly with acetyl isothiocyanate, generated in situ, to give the corresponding *N*-acetylthioxocarbamates **1** in good yields. The results are summarized in Table 1. The addition reaction was applicable to not only simple primary and secondary alcohols (runs 1, 3, 6, and 8) but also the mono-protected vicinal diol (run 9) and steroids (runs 10 and 11). With

Table 1. *N*-Acylthioxocarbamates **1** and its Deoxygenated Products **2**

Run	R^1	Alcohol	Adduct **1** Yield (%)	Reagent[a]	Temp. (°C)	Time	Product **2** Yield (GC, %)
1	Me	1-Dodecanol	48 (**1a**)	Sn	140	20 min	Dodecane (**2a**) (51)
2				Si	80	10 min	(83)
3	Me	2-Dodecanol	63 (**1b**)	Sn	80	20 min	Dodecane (**2a**) (88)
4				Si	r.t.	10 min	82 (88)
5				Si[b]	80	10 min	(85)
6	Me	Cyclododecanol	74 (**1c**)	Sn	80	20 min	Cyclododecane (**2c**) (88)
7				Si	r.t.	10 min	91
8	Me	3-Phenyl-2-propanol	61 (**1d**)	Sn	80	20 min	Propylbenzene (**2d**) (84)
9	Me	*trans*-1,2-Cyclohexanediol monobenzoate	40 (**1e**)	Sn	80	30 min	Cyclohexyl benzoate (**2e**) 96
10	Me	Cholest-5-en-3β-ol	62 (**1f**)	Sn	80	3 h	Cholest-5-ene (**2f**) 60
11	Me	3α-Hydroxy-5α-androstan-17-one	75 (**1g**)	Sn	80	1 h	5α-androstan-17-one (**2g**) 95
12				Si	r.t.	10 min	67 (81)
13	MeO	2-Dodecanol	66 (**1h**)	Sn	80	20 min	Dodecane (**2a**) (86)
14	4-MeOC_6H_4	2-Dodecanol	97 (**1i**)	Sn	80	1 h	Dodecane (**2a**) (84)

[a] Sn: Bu_3SnH/AIBN, Si: Ph_3SiH/Et_3B.

[b] Ph_2SiH_2 was used instead of Ph_3SiH.

Table 2. Characteristic Data of *N*-Acylthioxocarbamates **1**

Compound[a]	mp (°C) (solvent)	IR[b] ν (cm^{-1})	^1H NMR ($CDCl_3$) δ, J (Hz)	^{13}C NMR ($CDCl_3$) δ
1a	64–65 (hexane)	3212, 3034, 2922, 2856, 1703, 1542, 1470, 1403, 1308, 1214, 1054	0.88 (t, 3H, J = 6.8), 1.26–1.45 (m, 18H), 1.80 (m, 2H), 2.39 (s, 3H), 4.52 (t, 2H, J = 6.8), 8.54 (br s, 1H)	13.95, 22.63, 25.25, 25.86, 28.24, 29.17, 29.29, 29.44, 29.52, 29.60, 31.91, 73.48, 168.43, 188.71
1b	oil	3235, 2929, 2859, 1716, 1528, 1373, 1286, 1197, 1034	0.87 (t, 3H, J = 6.8), 1.24–1.34 (m, 16H), 1.36 (d, 3H, J = 6.2), 1.58–1.84 (m, 2H), 2.37 (s, 3H), 5.5 (m, 1H), 8.45 (br s, 1H)	13.95, 19.17, 22.61, 25.17, 25.45, 29.26, 29.38, 29.43, 29.51, 29.54, 31.87, 35.54, 81.25, 168.52, 188.03
1c	108–109 (hexane)	3215, 3030, 2935, 2861, 1712, 1532, 1445, 1379, 1286, 1209, 1081, 1039	1.30–1.89 (m, 22H), 2.37 (s, 3H), 5.63 (m, 1H), 8.49 (br s, 1H)	21.14, 23.45, 23.63, 24.10, 24.35, 25.44, 28.94, 83.15, 168.46, 188.21
1d	oil	3232, 2983, 1714, 1505, 1371, 1282, 1191, 1131, 1048	1.39 (d, 3H, J = 6.3), 2.33 (s, 3H), 2.93 (dd, 1H, J = 13.7, 2.9), 3.18 (dd, 1H, J = 13.7, 3.2), 5.75 (m, 1H), 7.22–7.34 (m, 5H), 8.47 (br s, 1H)	18.70, 25.53, 41.47, 80.92, 126.83, 128.56, 129.37, 136.53, 168.66, 187.61
1e	oil	3240, 2945, 2867, 1720, 1513, 1278, 1059	1.42–2.38 (m, 8H), 2.31 (s, 3H), 5.25 (dt, 1H, J = 9.7, 4.7), 5.65 (dt, 1H, J = 9.7, 5.1), 7.43–8.01 (m, 5H), 8.38 (br s, 1H)	23.32, 25.32, 29.47, 30.26, 73.85, 82.38, 128.46, 129.79, 130.28, 133.11, 165.89, 168.57, 187.52
1f	181–183 (benzene)	3240, 2950, 1710, 1493, 1375, 1262, 1195, 1044	0.69 (s, 3H), 0.87 (d, 6H, J = 6.6), 0.92 (d, 3H, J = 6.5), 1.00–2.60 (m, 28H), 1.05 (s, 3H), 2.39 (s, 3H), 5.22 (m, 1H), 5.44 (m, 1H), 8.45 (br s, 1H)	11.86, 18.73, 19.29, 21.07, 22.53, 22.78, 23.83, 24.28, 25.64, 27.28, 28.00, 28.20, 31.89, 31.93, 35.78, 36.21, 36.62, 36.80, 37.46, 39.54, 39.75, 42.36, 50.05, 56.20, 56.72, 83.25, 123.62, 138.84, 168.65, 187.47
1g	159–160 (hexane)	3146, 2935, 1730, 1511, 1338, 1278, 1198, 1027	0.84 (s, 3H), 0.86 (s, 3H), 0.80–2.47 (m, 22H), 2.36 (s, 3H), 5.64 (m, 1H), 8.53 (br s, 1H)	11.44, 13.81, 20.11, 21.71, 25.53, 25.69, 27.97, 30.73, 31.51, 32.17, 33.18, 35.05, 35.80, 35.94, 40.54, 47.75, 51.41, 54.42, 80.50, 167.78, 187.84, 221.00
1h	oil	3265, 2929, 2858, 1774, 1518, 1374, 1260, 1175, 1058	0.87 (t, 3H, J = 6.9), 1.24–1.44 (m, 16H), 1.36 (d, 3H, J = 6.2), 1.56–1.84 (m, 2H), 3.76 (s, 3H), 5.50 (m, 1H), 8.06 (br s, 1H)	13.96, 19.10, 22.63, 25.08, 29.29, 29.39, 29.46, 29.54, 29.57, 31.90, 35.53, 52.89, 81.16, 149.39, 188.25
1i	oil	3277, 2929, 2857, 1707, 1608, 1498, 1364, 1263, 1179, 1123, 1030	0.87 (t, 3H, J = 6.8), 1.20–1.46 (m, 16H), 1.41 (d, 3H, J = 6.3), 1.60–1.90 (m, 2H), 3.84 (s, 3H), 5.50 (m, 1H), 6.96, 7.80 (AA'BB'q, 4H, J = 8.9), 8.96 (br s, 1H)	13.96, 19.13, 22.63, 25.11, 29.29, 29.41, 29.46, 29.55, 29.57, 31.89, 35.54, 55.52, 81.55, 114.32, 125.49, 129.90, 161.77, 163.68, 189.48

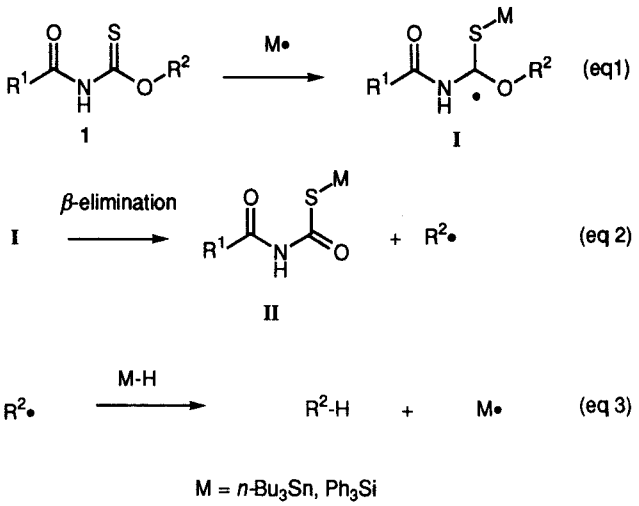
[a] Satisfactory HRMS values obtained: ± 0.0119 amu.

[b] KBr discs for solids, neat for oil.

1-dodecanol and *trans*-2-hydroxycyclohexyl benzoate (runs 1 and 9), the yields of adducts **1** were somewhat lower even if 2 equivalents of acetyl isothiocyanate was used. Tertiary alcohols, such as 1-adamantanol, gave a complex mixture and the desired adduct **1** was isolated only in 5% yield.

All products gave satisfactory spectroscopic and analytical data (Table 2). It was confirmed by ^1H and ^{13}C NMR spectroscopic analyses that thiol carbamate, a rearranged isomer, was not involved in **1** at all under the conditions used. This procedure was found to be a simple and convenient method for the conversion of primary and secondary alcohols to their *O*-thiocarbonyl derivatives without the need for any catalyst.

A radical deoxygenation of *N*-acylthioxocarbamates **1** with tributylstannane or various organosilanes was examined using AIBN or Et_3B as an initiator. The reaction course was monitored by GC and TLC analysis. Product analyses were carried out by comparison with authentic samples using GC and GC/MS and both of the isolated yields and the yields obtained by GC using tridecane or pentadecane as an internal standard are also shown in Table 1. According to the original Barton–McCombie theory,[7] the reaction pathway is postulated to be that shown in Scheme 1.



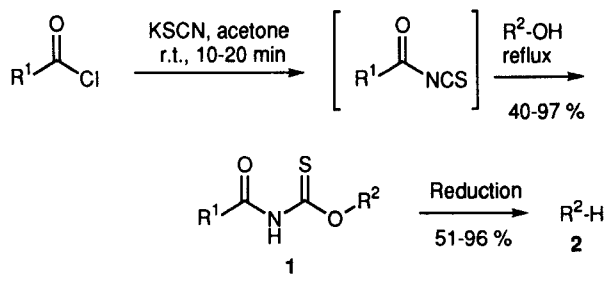
Scheme 1

The reaction of 2-dodecyl *N*-acetylthioxocarbamate **(1b)** and tributylstannane (2 equiv) in the presence of AIBN (20 mol%) at 80 °C gave dodecane in 88% yield (run 3). We also examined Et_3B induced[8] deoxygenation of **1b**. Treatment of **1b** with triphenylsilane (2 equiv) and Et_3B (1.2 equiv) in benzene at room temperature gave dodecane in 88% yield (run 4). An injection of dry oxygen

as air via syringe was required in order to complete the reaction. When a catalytic amount of Et_3B was used, the yield of product was reduced to 65%. In Et_3B induced reactions, tributylstannane, triethylsilane, and diphenylsilane were also introduced as a hydrogen donor. Tributylstannane gave a somewhat lower yield, while triethylsilane was unreactive. Diphenylsilane needed a higher temperature (80°C) to obtain a satisfactory amount of the product (run 5). In the silane-reduction, the results can be rationalized by the bond dissociation energy of Si–H bonding. In contrast to Barton's report,[9] triphenylsilane was the most effective reducing agent in our Et_3B initiated deoxygenation reaction. Consequently, the following two conditions were adopted for further investigations: tributylstannane/AIBN (condition A) and triphenylsilane/Et_3B (condition B).

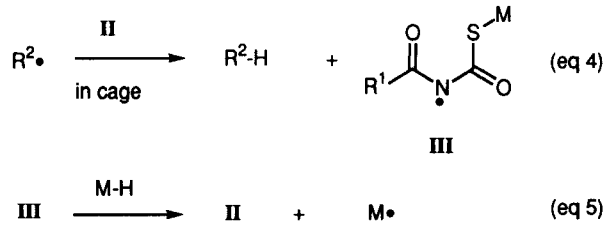
Other *N*-acyl groups were also examined, and only the methoxycarbonyl **(1h)** and 4-methoxybenzoyl **(1i)** derivatives were deoxygenated using condition A in 86 and 84% yields, respectively (runs 13 and 14). These adducts, **1h** and **1i**, were also subjected to condition B and dodecane was obtained in 75 and 5% yields, respectively. Taking into consideration the remarkable substituent effects of R^1 in these acyl groups it was assumed that the electronic nature of R^1 controlled the reactivity of the thiocarbonyl group toward metal radicals (eq 1). From these findings, *N*-acetyl derivatives were thought to be most suitable for deoxygenation reactions using both conditions A and B.

The *N*-acetyl derivatives of other alcohols were also reduced using the above two conditions to give deoxygenated products **2** in good yields (Scheme 2). This deoxygenation reaction showed high chemoselectivity. For example, the reactions of **1** bearing double bond, ester, and carbonyl functionalities afforded only the deoxygenated products, leaving the other functional groups intact under the reaction conditions employed (runs 9–12). Moreover, the elimination reactions, which were often significant side reactions under ionic conditions to give olefins, were not observed at all. In the case of 1-dodecyl *N*-acetylthioxocarbamate **(1a)**, a higher temperature was required to obtain an acceptable yield using both conditions (runs 1 and 2). This was probably due to the lower stability of primary relative to secondary carbon radicals (eq 2).



Scheme 2

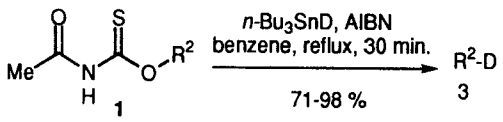
As an application of this reaction, we investigated the deoxydeuteration of *N*-acetylthioxocarbamate **1**. Thus, 3-phenyl-2-propyl *N*-acetylthioxocarbamate **(1d)** was reduced under condition A, in which tributyldeuteriostannane (Bu_3SnD) was used, and 1-phenylpropane-2-*d* **(3d)** was obtained in 84% yield. ^1H and ^{13}C NMR spectra of isolated **3d** confirmed that a regiospecific and substantially quantitative deuteration was achieved. The isotopic distribution was also determined by mass spectrometry using selected ion monitoring (SIM) mode, and deuterium incorporation was found to be 99% for **3d**. However, only 10% of deuterium incorporation for **3d** was observed in the deoxydeuteration of **1d** using triphenyldeuteriosilane/Et_3B suggesting that other hydrogen sources existed. We would like to propose the following hypothesis for the reduction of the R^2 radical and regeneration of a metal radical as a chain carrier (Scheme 3). Namely, hydrogen abstraction by the R^2 radical from the metal hydride (eq 3) and from the intramolecular nitrogen–hydrogen moiety (eq 4), which is assumed to occur in a cage, would be competitive. Under condition B, the reaction shown in equation 4 occurred predominantly. In fact, treatment of **1d** with EtOD in order to replace the H atom of the N–H moiety with deuterium, followed by deoxydeuteration under similar conditions gave 71% of **3d** with 51% deuterium content. Furthermore, we checked the deuterium content of the product from the 4-fluorophenoxythiocarbonyl derivative (Barton's procedure),[9] in which an intramolecular active hydrogen was not involved. 1-Phenyl-2-propyl 4-fluorophenylthioxocarbonate was treated with deuteriotriphenylsilane using Et_3B as an initiator to afford 66% yield of **3d** with a deuterium content of 84%, which was still not as high. This result indicates that the hydrogen source is not only the N–H moiety of the starting material but also another source such as an ethyl radical, which is generated from Et_3B and undergoes a β-elimination to give a hydrogen radical and ethylene. From these findings, the Bu_3SnD/AIBN system was the most suitable for deoxydeuteration of **1**.



Scheme 3

Other *N*-acetylthioxocarbamates **1** were also subjected to the deoxygenation reaction using Bu_3SnD/AIBN to afford the deuterated products **3** in good yields (Scheme 4). The yields and deuterium content of deuterated products **3** are shown in Table 3 and the physical and spectral data are listed in Table 4. The reaction revealed high regioselectivity. In the course of the reaction, any radical rearrangements to form the more stable radicals, such as secondary (run 1), benzyl (run 3), and allyl (run 5) radicals, were not observed. Deuterium incorporation was also very high, indicating that deuterium abstraction by the R^2 radical occurred exclusively from Bu_3SnD (eq 3). In the reaction of the primary derivative **1a**, however, the deuterium content of **3a** was slightly lower because

higher temperatures caused intramolecular hydrogen abstraction by the reactive primary alkyl radical (eq 4). The stereoselectivity of the deuteration was examined by ^{1}H NMR integration of **3e** and it was found that the ratio of equatorial/axial deuterium substitution was 7:3. Thus, the approach of Bu_3SnD to the radical center from the equatorial side predominated but was not significantly stereoselective.



Scheme 4

Table 3. Deuterated Products **3** Obtained by the Reduction of *N*-Acetylthionocarbamates **1** Using Bu_3SnD/AIBN

Run	Adduct **1**	Deuterium Incorporation (%)	Product **3** Yield (GC, %)
1	**1a**	89	**3a** 58 (71)
2	**1b**	99	**3b** 79 (80)
3	**1d**	99	**3d** 17 (84)
4	**1e**	99	**3e** 88
5	**1f**	97	**3f** 74
6	**1g**	95	**3g** 98

In summary, we have shown that acetyl isothiocyanate, prepared in situ from acetyl chloride and potassium thiocyanate, reacts readily with a wide range of alcohols, providing the corresponding *N*-acetylthioxocarbamates in good yields and these adducts were effectively deoxygenated using tributylstannane/AIBN or triphenylsilane/Et_3B systems. The procedure using Bu_3SnD was found to be applicable to the convenient deoxydeuteration of alcohols. The reaction displays excellent regio- and chemoselectivity and the deuterium content of the product was also satisfactory.[11]

Melting points were determined on a Yamato MP-21 melting point apparatus and are uncorrected. Microdistillation was performed on a SHIBATA GTO-250RS glass tube oven. Flash chromatography following the method of Still et al.[10] with Merck silica gel 60 (230–400 mesh) was used. ^{1}H and ^{13}C NMR spectra were measured in $CDCl_3$ solutions on a Varian UNITY-400 spectrometer. All chemical shifts are reported as δ values relative to residual $CHCl_3$ ($\delta = 7.26$) and the central peak of $CDCl_3$ ($\delta = 77.00$). IR spectra were recorded on a Perkin–Elmer 1720X IR spectrometer. GC analysis was performed on a Ohkura GC-103C and a GL Sciences GC-380 gas chromatograph using a 50 m × 0.25 mm methyl silicone capillary column (Quadrex). Mass spectra were obtained on a JEOL JMS-AX-500 spectrometer with a DA7000 data system. GC/MS was measured with the direct combination of GLC (Hewlett-Packard GC 890 Series II with a 25 m × 0.25 mm methyl silicone capillary column) and a JEOL JMS-AX-500 spectrometer. Selected ion monitoring (SIM) method was used to determine isotopic distribution in the deuterated products, focusing on $M^{\bullet+}$ and $(M+1)^{\bullet+}$ ions.

Most of the starting materials and reagents were commercial products and were purified if necessary. Bu_3SnD and Ph_3SiD were prepared by reducing the corresponding chlorides with $LiAlD_4$ in Et_2O or THF. Solvents were distilled over Na in the presence of benzophenone.

2-Dodecyl *N*-Acetylthioxocarbamate (1b); Typical Procedure:
A mixture of dried KSCN (0.58 g, 6 mmol) and AcCl (0.39 g, 5 mmol) in anhydr. acetone (5 mL) was stirred for 10 min, followed by addition of 2-dodecanol (0.93 g, 5 mmol), and the mixture refluxed overnight. After evaporation of acetone in vacuo, the residue was partitioned between CH_2Cl_2 (30 mL) and H_2O (30 mL), and the organic phase separated and dried ($MgSO_4$). After removal of solvent, the residue was chromatographed on silica gel. Elution with hexane/EtOAc (9:1) gave a pale yellow oil, characterized as **1b**; yield: 0.91 g (63%).

Reduction of *N*-Acetylthioxocarbamate 1 Using Bu_3SnH/AIBN (Condition A); Cholest-5-ene (2f); Typical Procedure:
A solution of *N*-acetylthioxocarbamate **1f** (97.6 mg, 0.2 mmol), Bu_3SnH (58.2 mg, 0.4 mmol), and AIBN (6.6 mg, 0.04 mmol) in benzene (5 mL) was refluxed under Ar for 3 h. The progress of the reaction was monitored by GC and TLC analyses. The crude product obtained after removal of the solvent was purified by flash chromatography (silica gel, hexane) affording pure **2f**; yield: 44.6 mg (60%). An analytical sample was obtained by recrystallization from EtOH as colorless needles; mp 89–90 °C (Lit.[2] mp 90–92 °C).

Table 4. Physical and Spectral Data of Deuterated Products **3**

Compound[a]	mp (°C) (solvent)	^{1}H NMR ($CDCl_3$) δ, J (Hz)	^{13}C NMR ($CDCl_3$) δ, J (Hz)
3a	oil	0.88 (m, 5H), 1.26 (m, 20H)	13.71 (t, J = 19.0), 14.02, 22.58, 22.66, 29.35, 29.66, 29.70, 31.91, 31.93
3b	oil	0.88 (m, 5H), 1.26 (m, 20H)	13.88, 13.99, 22.26 (t, J = 19.1), 22.66, 29.32, 29.35, 29.66, 29.70, 31.84, 31.94
3d	oil	0.94 (dt, 3H, J = 7.3, 1.0), 1.63 (m, 1H), 2.59 (d, 2H, J = 7.7), 7.16–7.30 (m, 5H)	13.59, 24.02 (t, J = 19.1), 38.05, 125.64, 128.25, 128.49, 142.75
3e	oil	1.32–1.50 (m, 3H), 1.58 (m, 2.7H), 1.79 (m, 2H), 1.94 (m, 1.3H), 5.03 (m, 1H), 7.43–8.05 (m, 5H)	23.58, 23.67, 31.35 (t, J = 20.0), 31.68, 73.00, 128.25, 129.57, 131.34, 132.57, 166.01
3f	85–87 (EtOH)	0.67 (s, 3H), 0.86 (d, 3H, J = 6.6), 0.87 (d, 3H, J = 6.6), 0.90–2.27 (m, 29H), 0.91 (d, 3H, J = 6.5), 0.99 (s, 3H), 5.27 (m, 1H)	11.93, 18.82, 19.45, 20.92, 22.53, 22.58, 22.74, 23.97, 24.35, 27.73 (t, J = 19.0), 28.04, 28.25, 32.02, 32.08, 32.90, 35.85, 36.38, 37.68, 39.66, 40.02, 40.10, 42.51, 50.91, 56.50, 57.11, 119.02, 143.85
3g	115–116 (EtOH)	0.68–2.46 (m, 2H), 0.80 (s, 3H), 0.85 (s, 3H)	12.20, 13.86, 20.16, 21.79, 22.78, 26.35 (t, J = 19.1), 28.85, 28.98, 31.08, 31.80, 35.26, 35.85, 36.53, 38.76, 47.22, 47.83, 51.78, 55.10, 220.99

[a] Satisfactory HRMS values obtained: ± 0.0049 amu.

Reduction of 1 with Ph_3SiH/Et_3B (Condition B); 5α-Androstan-17-one; (2g); *Typical Procedure*:
A hexane solution of Et_3B (1.0 M, 0.3 mL, 0.3 mmol) was added to a solution of **1g** (98.0 mg, 0.25 mmol) and Ph_3SiH (0.13 g, 0.5 mmol) in benzene (5 mL) at r.t. under Ar atmosphere and dry air (30 mL) was introduced into the solution through a septum over 5 min. After stirring at r.t. for 10 min, the mixture was concentrated and was submitted to column chromatography on silica gel (hexane/EtOAc, 95:5) to give **2g**; yield: 46.3 mg (67%); mp 119–120°C; colorless plates (EtOH).

^{1}H NMR ($CDCl_3$): δ = 0.80 (s, 3H, CH_3), 0.85 (s, 3H, CH_3), 0.68–2.46 (m, 24H).

^{13}C NMR ($CDCl_3$): δ = 12.22, 13.86, 20.17, 21.79, 22.19, 26.79, 28.86, 29.09, 31.09, 31.82, 35.29, 35.83, 36.54, 38.79, 47.26, 47.83, 51.80, 55.13, 220.86.

HRMS: *m/z* for $C_{19}H_{30}O$, calc.: 274.2297; found: 274.2339.

Deoxydeuteration of 1 with Bu_3SnD/AIBN; 2-Deuterio-1-phenylpropane (3d); Typical Procedure:
A mixture of **1d** (0.12 g, 0.5 mmol), Bu_3SnD (0.29 g, 1 mmol), and AIBN (0.016 g, 0.1 mmol) in benzene (10 mL) was refluxed under Ar for 30 min. Direct GC analysis of the mixture showed the formation of 1-phenylpropane-2-*d* (**3d**) in 84% yield. Isolation of the product was carried out by using a glass tube oven (170–200°C) to give **3d**; yield: 20.8 mg (17%). The regioselectivity of deuteration was confirmed by ^{1}H and ^{13}C NMR spectrometry (Table 4). From the GC/MS analysis of the crude or isolated product, the relative ratio of $PhCH_2CHDCH_3/PhCH_2CH_2CH_3$ = 99:1 was determined by measuring the relative abundance of the corresponding $M^{\bullet+}$ and $(M+1)M^{\bullet+}$ ions.

1-Phenyl-2-propenyl 4-Fluorophenylthioxocarbonate (Barton's Procedure):
To a stirred solution of 1-phenyl-2-propanol (0.68 g, 5 mmol) and pyridine (0.44 g, 5.5 mmol) in CH_2Cl_2 (5 mL) was added dropwise 4-fluorophenyl chlorothioxocarbonate (0.95 g, 5 mmol) in CH_2Cl_2 (5 mL) during 15 min. After 2 h, the reaction was quenched by the addition of H_2O (20 mL), and the organic phase was separated and dried ($MgSO_4$). After removal of the solvent in vacuo, the residue was chromatographed on silica gel using hexane/EtOAc (95:5). Evaporation of appropriate fractions gave 1-phenyl-2-propyl 4-fluorophenylthioxocarbonate; yield: 1.39 g (96%).

^{1}H NMR ($CDCl_3$): δ = 1.41 (d, 3H, J = 6.4 Hz, Me), 2.91 (dd, 1H, J = 13.6, 7.2 Hz, CH_2), 3.20 (dd, 1H, J = 13.5, 6.1 Hz, CH_2), 5.58 (m, 1H, CH), 6.99–7.34 (m, 9H_{arom}).

^{13}C NMR ($CDCl_3$): δ = 18.61, 41.76, 82.55, 116.12 (d, J = 23.7 Hz), 123.52 (d, J = 8.4 Hz), 126.82, 128.55, 129.55, 136.75, 149.31 (d, J = 3.1 Hz), 160.73 (d, J = 245.5 Hz), 194.37.

HRMS: *m/z* $C_{16}H_{15}O_2FS$, calc.: 290.0777; found: 290.0776.

This study was partially supported by Special Coordination Funds of the Science and Technology Agency of the Japanese Government.

(1) Hartwig, W. *Tetrahedron* **1983**, *39*, 2609.
(2) Barton, D.H.R.; McCombie, S.W. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574.
(3) Robins, M.J.; Wilson, J.S. *J. Am. Chem. Soc.* **1981**, *103*, 932. Robins, M.J.; Wilson, J.S.; Hansske, F. *J. Am. Chem. Soc.* **1983**, *105*, 4059.
(4) Pankiewicz, K.; Matsuda, A.; Watanabe, K.A. *J. Org. Chem.* **1982**, *47*, 485.
(5) Nishiyama, K.; Oba, M.; Oshimi, M.; Sugawara, T.; Ueno, R. *Tetrahedron Lett.* **1993**, *34*, 3745.
(6) Barton, D.H.R.; Ollis, W.D. In *Comprehensive Organic Chemistry*; Pergamon: Oxford, 1979; Vol. 3, p461.
(7) Barton, D.H.R.; Jang, D.O.; Jaszberenyi, J.Cs. *Tetrahedron Lett.* **1990**, *31*, 3991.
(8) Nozaki, K.; Oshima, K.; Utimoto, K. *Tetrahedron Lett.* **1988**, *29*, 6125. Nozaki, K.; Oshima, K.; Utimoto, K. *Tetrahedron* **1989**, *45*, 923.
(9) Barton, D.H.R.; Jang, D.O.; Jaszberenyi, J.Cs. *Tetrahedron Lett.* **1990**, *31*, 4681.
(10) Still, W.C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.
(11) The deuterium content of the products, reported by us,[5] was not as good. The revised results will be submitted elsewhere.