

HIGH REGIO- AND STEREOSELECTIVITY IN FACILE ONE-POT CONVERSION OF TAXOIDS TO THE PRIMARY ALCOHOLS: PRECURSORS FOR THE SYNTHESIS OF 4-DEACETOXPACILITAXEL AND ANALOGUES

Qian Cheng, Tohru Horiguchi, Marina Yamaguchi, and Takayuki Oritani*

Laboratory of Applied Bioorganic Chemistry, Graduate School of Agricultural Science, Tohoku University, 1-1 Tsutsumidori-Amamiyamachi, Aoba-ku, Sendai 981-8555, Japan. Email: oritani@biochem.tohoku.ac.jp

Abstract-The conversion of alkali metal hydroxy base sensitive taxoids bearing ester groups to the corresponding primary alcohols in a facile one-pot protocol has been reported. This process which involves two steps of hydroboration and oxidation, using a mixture of NMO and TBHP (2:1), which possesses high regio- and stereoselectivity was first established. Proof of the chemistry used in the preparation of a precursor for the synthesis of a 4-deacetytaxel analogue has also been presented.

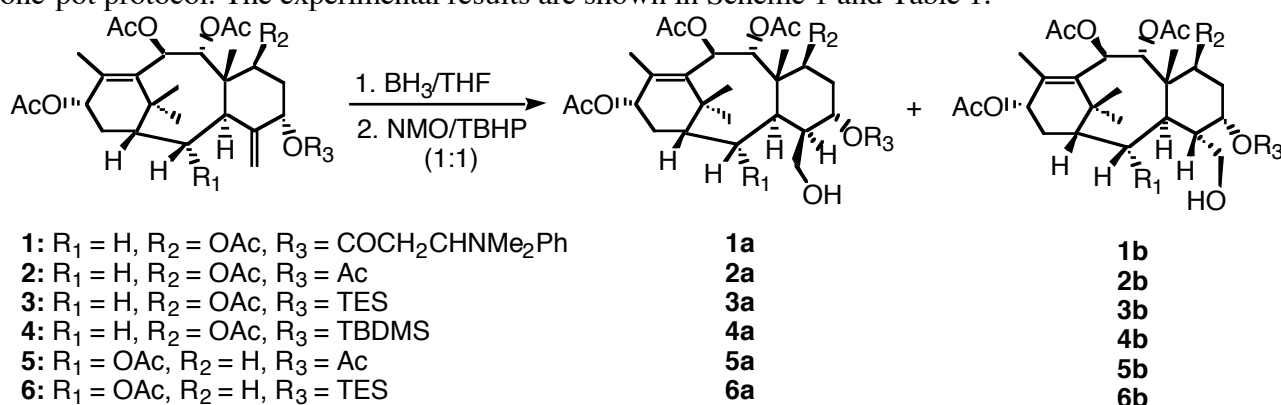
INTRODUCTION

Diterpenoid paclitaxel¹ (Taxol[®]) has been proven to be a powerful therapeutic drug for cancer chemotherapy, and also exhibits potent antitumor activity against various cancers that have been uneffectively treated by existing chemotherapeutic drugs.^{2,3} Paclitaxel was approved by the FDA for the treatment of advanced ovarian cancer and breast cancer in 1994 and also for the second-line treatment of AIDS related Kaposi's sarcoma in 1997.⁴ Since its discovery in 1960's, a large amount of paclitaxel analogues have been synthesized for biological and medicinal research,⁵ as well as structure-activity relationship (SAR) studies.⁶ Due to our studies on chemical conversions of natural taxoids to paclitaxel and analogues for pharmaceutical uses,⁷ a facile one-pot protocol for the conversion of alkali metal hydroxy base sensitive taxoids bearing functional groups to the corresponding primary alcohols has been established and presented here. This process involves hydroboration and oxidation, using 4-methylmorpholine *N*-oxide (NMO) and *t*-butyl hydroperoxide (TBHP) two steps which possess high regio- and stereoselectivity.

DISCUSSION AND RESULTS

Hydroboration, in particular a regio- and stereoselective hydroboration, of a carbon double bond with borane and boron compounds leading to organoboranes, which were subsequently oxidized with hydrogen peroxide under an aqueous NaOH condition in order to give primary alcohols, has been widely used in

organic synthesis.⁸ Unfortunately, this reaction has not been efficient in the hydroboration-oxidation of taxoids bearing ester groups due to ester hydrolysis.⁹ In addition, trimethylamine *N*-oxide was also observed to be ineffective for oxidation of the organoborane taxoids to primary alcohol in our experiments due to the comparatively lower product yield.¹⁰ However, it was interesting to find that 4-methylmorpholine *N*-oxide (NMO) accompanied by *t*-butyl hydroperoxide (TBHP) was efficient in the oxidation reaction of organoborane taxoids to the corresponding primary alcohols. And the hydroboration of taxoids with borane-tetrahydrofuran complex followed by oxidation with NMO and TBHP two steps could be performed in one-pot protocol. The experimental results are shown in Scheme 1 and Table 1.



Scheme 1

Table 1. One-pot conversion of taxoids to the corresponding primary alcohols.

Compound	β -CH ₂ OH : α -CH ₂ OH	Isolated yield (%)
	(a) : (b) ^a	
1	99 : 1	66 ^c
2	5 : 1	84
3	9 : 1	81
4	20 : 1	77
5	100 : 0 ^b	78
6	100 : 0 ^b	73

a: The ratio of α - and β -isomers was determined by ¹H-NMR (500 MHz) of a crude mixture.

b: α -Isomers (**5b**) and (**6b**) were not found by ¹H-NMR (500 MHz) of a crude mixture

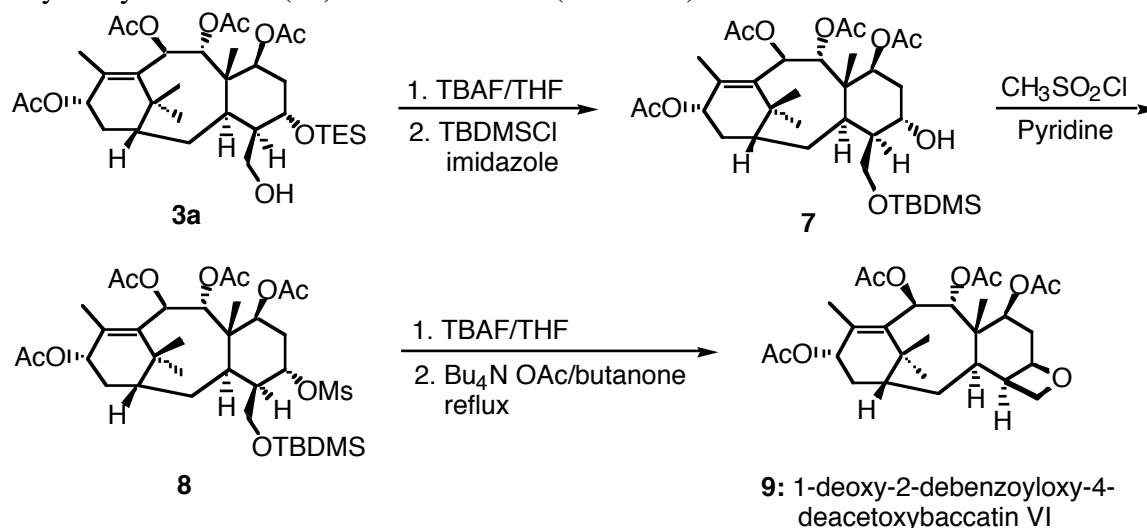
c: Hydroboration was completed in 3 h.

Several kinds of taxoids were introduced in the experiment. The results, shown in Table 1, indicate that the hydroboration with borane took place only at C-4(20) double bond and that the β -isomers as major products were obtained in all experimental examples. The ratio of β - and α -isomers of the products was influenced by the substituents of 2- and 5- positions as well the stereoskeleton of taxinine and derivatives. 2-Deacetoxy taxinine J derivatives (**1**) and (**4**), bearing the bulk substituents at the C-5 position, gave high stereoselectivity in the 99:1 and 20:1 ratios of products respectively, while compounds (**2**) and (**3**) afforded mediate stereoselectivity in both 5:1 and 9:1 ratios of products. This may arise from the fact that the α -face is most likely favorable to be attacked by boron reagents in a specially rigid taxinine skeleton. In fact, similar stereochemistry has been observed in both dihydroxylation and epoxidation of C4(20) double bond in taxoids using osmium tetroxide (OsO₄)¹¹ and *m*-chloroperoxybenzoic acid (*m*CPBA)¹² respectively. All

products were unambiguously identified by NMR studies including 2D-NMR experiments. NOESY correlations of H-20a to H-2 β , H-5 and H₃-19, and H-3 to H-4 α were observed in all major isomers bearing 4 β -hydroxymethylene group. Whereas all minor isomers bearing 4 α -hydroxymethylene group gave NOESY correlations of H-4 α to H-2 β , H-5, H-6 β and H₃-19, and H-3 to H-20b. Similarly, respective taxinine derivatives (**5**) and (**6**) afforded only the β -isomers (**5a**) and (**6a**) as the reaction products which were further confirmed by NOESY correlations of H-20a to H-2 β and H₃-19, and H-3 to H-4 α . Formation of only the β -isomers (**5a**) and (**6a**) from taxinine derivatives (**5**) and (**6**) respectively might be due to an acetoxy group possessing α -orientation located at C-2 which is not likely to be attacked by boron reagents from β -face in a rigid taxinine skeleton.¹³

The hydroboration of taxoid (**1**) using a bulk 9-BBN instead of borane resulted in the recovery of the starting material probably due to the hinderance of the C4(20) double bond which was not likely to be attacked by the bulk reagent 9-BBN.¹⁴ Whereas taxoid (**2**) was treated with 9-BBN followed by the addition of NMO and TBHP under refluxing for 2 h to furnish only (**2a**) in a 48% yield. In addition, we observed that the oxidation of organoborane taxoid in the 1,4-dioxane or THF-1,4-dioxane (1:2) was preferable to that of in THF at the refluxing temperature. This might indicate that a higher refluxing temperature quickens the oxidation process.

A large number of paclitaxel analogues having been synthesized for structure-activity relationships (SAR) studies. It is known that the removal of a 4-acetyl group leads to a marked decrease in the bioactivity of paclitaxel.⁶ Although the synthesis of 4-deacetytpaclitaxel derived from paclitaxel has been reported by Kingston and his co-workers,¹⁵ in depth chemical and medicinal studies on 4-deacetytpaclitaxels have not yet appeared in literature due to the fact that 4-deacetytpaclitaxel analogues are difficult to prepare. The above-demonstrated chemistry was proposed in order to provide a useful method for the synthesis of 4-deacetytpaclitaxels from available natural taxoids. Proof of the preparation of 1-deoxy-2-debenzoyloxy-4-deacetytbaccatin VI (**9**), a useful precursor for the synthesis of 4-deacetytpaclitaxel analogue, from the 4 β -hydroxymethylene taxoid (**3a**) is shown below. (Scheme 2).



Scheme 2

Deprotection of **3a** with tetrabutylammonium fluoride (TBAF, 1.0 M in THF) followed by a selective protection using *tert*-butyldimethylsilyl chloride gave 5 α -hydroxy taxoid (**7**) in an 81% yield, which was subsequently mesylated by methanesulfonyl chloride to afford the protected taxoid (**8**) in a 74% yield. The desired compound (**9**) was successfully obtained in a 61% yield from (**8**) following the previously established methods.^{7c} The structure and stereochemistry of (**9**) were unambiguously determined by wide NMR studies including COSY and NOESY.

In summary, the facile conversion of the alkali metal hydroxy base sensitive taxoids bearing ester groups to the corresponding primary alcohols in a highly regio- and stereoselective one-pot protocol which involves two steps of hydroboration and oxidation using NMO and TBHP has been established.

EXPERIMENTAL

All anhydrous reactions were performed in oven-dried glassware under nitrogen. Tetrahydrofuran and ether were distilled from sodium and benzophenone. Dichloromethane was refluxed and distilled from CaH₂ under nitrogen. Chromatography was carried out on Merck silica gel 60 (230-400 mesh). Preparative TLC was performed on Merck silica gel 60 F₂₅₄ plates (0.85 mm thickness). ¹H-NMR (500 MHz), ¹³C-NMR (125 MHz) and 2D-NMR were performed on Varian Unity INOVA 500 spectrometer in CDCl₃ using TMS as an internal standard. Chemical shifts are expressed in parts per million (ppm) and coupling constants (*J*) are given in Hertz(Hz). Optical rotation was recorded by a Horiba SEPA-300 polarimeter. HRMS (EI and FAB) were measured by a JEOL JMS-700 spectrometer. All commercially available reagents were used without further purification. The natural 2-deacetoxy-5-(3'-dimethylamino-3'-phenylpropionoxy)taxinine J¹⁶ 2-deacetoxydecinnamoyltaxinine J¹⁷ and 5-decinnamoyltaxinine E¹⁸ were isolated from the Japanese yew *Taxus cuspidata* following the standard method¹⁹ in our laboratory. Taxoids (**2-4**) and (**5-6**) were prepared from 2-deacetoxydecinnamoyltaxinine J and 5-decinnamoyltaxinine E through acetylation with Ac₂O, silylation with TESC1 and TBDMSC1, respectively, according to the known established methods.^{7,11}

Typical procedure of one-pot hydroboration and oxidation of taxoids (1-6) to corresponding alcohols as follows:

A solution of taxoid (0.1 mmol) in THF (8 mL) was slowly injected BH₃-THF complex (0.2 mL, 1.0M in THF) under nitrogen at 0°C. The mixture was stirred for an additional 1-2 h (the reaction was monitored by TLC) at 0°C and then allowed to warm to rt, and methanol (0.2 mL) was added. After removal of THF, the residue was resolved in 1,4-dioxane (10 mL) followed by the addition of NMO (0.3 mmol) and TBHP (0.035 mL, 4.2M in toluene). The resulting mixture was refluxed for 2 h and cooled to rt. The mixture was extracted with EtOAc, and the combined organic phase was washed with water, brine, and dried over MgSO₄. After removal of the solvent, chromatography on silica gel with EtOAc-hexane (1:1) gave the product alcohols which are shown in Table 1.

1a: a colorless amorphous solid, [α]_D²⁵ +65.7° (c 1.10, CHCl₃). ¹H NMR δ_{H} 7.32-7.30 (m, 5H, Ph), 6.23 (d, 1H, *J* =10.8 Hz, H-10), 5.83 (d, 1H, *J* =10.8 Hz, H-9), 5.71(dd, 1H, *J* =10.3, 4.5 Hz, H-13), 5.67 (dd, 1H, *J* =11.6, 5.3 Hz, H-7), 4.87 (m, 1H, H-5), 3.85(t, 1H, *J* =7.0 Hz, H-3'), 3.62(dd, 1H, *J* =10.1, 2.6 Hz, H-20), 3.17 (dd, 1H, *J* =5.4, 4.8 Hz, H-3), 3.10 (dd, 1H, *J* =10.1, 3.5 Hz, H-20), 2.92 (dd, 1H,

$J=16.0, 7.0$ Hz, H-2'), 2.78 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.53 (dd, 1H, $J=16.0, 7.0$ Hz, H-2'), 2.22(s, 6H, NMe₂), 2.20(m, 1H, H-4), 2.16 (s, 3H, H₃-18), 2.07 (s, 3H, Ac), 2.06 (s, 3H, Ac), 2.00 (s, 3H, Ac), 1.99 (m, 1H, H-6), 1.98 (s, 3H, Ac), 1.89 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.72-1.70 (m, 2H, H-6, H-2), 1.60 (s, 3H, H₃-16), 1.10 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.06 (s, 3H, H₃-17), 0.89 (s, 3H, H₃-19). ¹³C NMR δ_c 171.32 (s, C=O), 170.31, 170.00, 169.62, 169.20 (4xs, 4xAc), 138.50 (s), 137.73 (s), 135.89 (s), 129.72 (d), 128.24 (d), 127.60 (d), 76.67 (d), 73.89 (d), 72.15 (d), 70.05 (d), 69.82 (d), 66.72 (t), 66.71 (d), 51.62 (d), 46.52 (s), 42.37 (q), 42.35 (q), 39.62 (d), 39.21 (d), 39.01 (s), 38.51 (t), 36.12 (t), 32.31 (t), 32.14 (q), 26.94 (t), 26.12 (q), 21.45, 21.01, 20.92, 20.81 (4xq, 4xAc), 15.92 (q), 12.70 (q). HMRS (FAB) calcd for C₃₉H₅₆O₁₁(M⁺+1) 700.3819, found 700.3821.

2a: a colorless amorphous solid, $[\alpha]_D^{25} +71.2^\circ$ (c 0.52, CHCl₃). ¹H NMR δ_H 6.21 (d, 1H, $J=10.5$ Hz, H-10), 5.84 (d, 1H, $J=10.5$ Hz, H-9), 5.71 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.67 (dd, 1H, $J=11.6, 5.3$ Hz, H-7), 4.64 (m, 1H, H-5), 3.64 (dd, 1H, $J=10.2, 2.6$ Hz, H-20), 3.21 (dd, 1H, $J=5.4, 4.8$ Hz, H-3), 3.13 (dd, 1H, $J=10.2, 3.5$ Hz, H-20), 2.76 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.21 (m, 1H, H-4), 2.16 (s, 3H, H₃-18), 2.09 (s, 3H, Ac), 2.07 (s, 3H, Ac), 2.01 (s, 3H, Ac), 2.00 (s+m, 4H, Ac+H-6), 1.98 (s, 3H, Ac), 1.88 (m, 1H, H-2), 1.79 (m, 1H, H-1), 1.71-1.69 (m, 2H, H-6, H-2), 1.60 (s, 3H, H₃-16), 1.11 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.05 (s, 3H, H₃-17), 0.88 (s, 3H, H₃-19). ¹³C NMR δ_c 170.54, 170.21, 170.01, 169.54, 169.20 (5xs, 5xAc), 137.69 (s), 135.92 (s), 76.84 (d), 73.92 (d), 72.23 (d), 70.24 (d), 69.92 (d), 65.48 (t), 51.27 (d), 45.78 (s), 39.72 (d), 39.40 (s), 38.91 (d), 36.15 (t), 32.15 (t), 31.98 (q), 26.56 (t), 26.17 (q), 21.40, 21.21, 20.93, 20.87, 20.81 (5xq, 5xAc), 16.10 (q), 13.01 (q). HMRS (EI) calcd for C₃₀H₄₄O₁₁ (M⁺) 580.2881, found 580.2287. **2b**: a colorless amorphous solid, $[\alpha]_D^{25} +114.3^\circ$ (c 0.10, CHCl₃). ¹H NMR δ_H 6.21 (d, 1H, $J=10.5$ Hz, H-10), 5.83 (d, 1H, $J=10.5$ Hz, H-9), 5.70 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.65 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 4.75 (m, 1H, H-5), 3.94 (dd, 1H, $J=10.1, 2.1$ Hz, H-20), 3.58 (dd, 1H, $J=10.1, 4.5$ Hz, H-20), 3.07 (dd, 1H, $J=9.5, 5.4$ Hz, H-3), 2.76 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.20 (m, 1H, H-4), 2.16 (s, 3H, H₃-18), 2.09 (s, 3H, Ac), 2.06 (s, 3H, Ac), 2.01 (s, 6H, 2Ac), 1.98 (s+m, 4H, Ac+H-6), 1.90 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.72-1.69 (m, 2H, H-6, H-2), 1.61 (s, 3H, H₃-16), 1.24 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.07 (s, 3H, H₃-17), 0.89 (s, 3H, H₃-19). ¹³C NMR δ_c 170.51, 170.32, 170.00, 169.89, 169.24 (5xs, 5xAc), 138.23 (s), 135.84 (s), 76.57 (d), 73.79 (d), 72.19 (d), 70.19 (d), 70.01 (d), 66.15 (t), 53.52 (d), 46.02 (s), 40.12 (d), 39.84 (d), 38.90 (s), 36.24 (t), 32.26 (t), 32.24 (q), 26.72 (t), 26.59 (q), 21.39, 21.27, 20.93, 20.90, 20.85 (5xq, 5xAc), 16.10 (q), 12.89 (q). HMRS (FAB) calcd for C₃₀H₄₅O₁₁ (M⁺+1) 581.2959, found 581.2963.

3a: a colorless amorphous solid, $[\alpha]_D^{25} +53.4^\circ$ (c 1.17, CHCl₃). ¹H NMR δ_H 6.24 (d, 1H, $J=10.7$ Hz, H-10), 5.84 (d, 1H, $J=10.7$ Hz, H-9), 5.71 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.67 (dd, 1H, $J=11.6, 5.3$ Hz, H-7), 3.61 (dd, 1H, $J=10.2, 2.5$ Hz, H-20), 3.37 (m, 1H, H-5), 3.15 (dd, 1H, $J=5.4, 4.8$ Hz, H-3), 3.08 (dd, 1H, $J=10.2, 3.5$ Hz, H-20), 2.78 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.36 (m, 1H, H-4), 2.18 (s, 3H, H₃-18), 2.07 (s, 3H, Ac), 2.05 (s, 3H, Ac), 2.01 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.97 (m, 1H, H-6), 1.89 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.71-1.69 (m, 2H, H-6, H-2), 1.57 (s, 3H, H₃-16),

1.09 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.04 (s, 3H, H₃-17), 0.97 (m, 9H, 3CH₃), 0.83 (s, 3H, H₃-19), 0.62 (m, 6H, 3CH₂). ¹³C NMR δ_c 170.46, 170.08, 169.70, 169.29 (4xs, 4xAc), 140.63 (s), 136.02 (s), 76.69 (d), 73.56 (d), 72.37 (d), 71.29 (d), 69.92 (d), 65.85 (t), 51.56 (d), 46.71 (s), 40.63 (d), 39.75 (d), 39.01 (s), 36.12 (t), 32.42 (q), 32.40 (t), 26.84 (t), 25.89 (q), 21.43, 21.02, 20.87, 20.81 (4xq, 4xAc), 16.14 (q), 13.04 (q), 6.74 (q), 4.34 (t). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3632. **3b**: a colorless amorphous solid, [α]_D²⁵ +87.3° (c 0.23, CHCl₃). ¹H NMR δ_H 6.23 (d, 1H, $J=10.8$ Hz, H-10), 5.83 (d, 1H, $J=10.8$ Hz, H-9), 5.70 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.65 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 3.87 (dd, 1H, $J=10.3, 2.2$ Hz, H-20), 3.54 (m, 1H, H-5), 3.52 (dd, 1H, $J=10.3, 4.6$ Hz, H-20), 3.02 (dd, 1H, $J=9.8, 5.4$ Hz, H-3), 2.76 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.29 (m, 1H, H-4), 2.18 (s, 3H, H₃-18), 2.08 (s, 3H, Ac), 2.06 (s, 3H, Ac), 2.00 (s, 3H, Ac), 1.98 (s+m, 4H, Ac+H-6), 1.91 (m, 1H, H-2), 1.79 (m, 1H, H-1), 1.71-1.69 (m, 2H, H-2, H-6), 1.54 (s, 3H, H₃-16), 1.24 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.05 (s, 3H, H₃-17), 0.98 (t, 9H, $J=7.0$ Hz, 3CH₃), 0.86 (s, 3H, H₃-18), 0.62 (q, 6H, $J=7.0$ Hz, 3CH₂). ¹³C NMR δ_c 170.31, 170.01, 169.87, 169.34 (4xs, 4xAc), 138.72 (s), 136.57 (s), 76.64 (d), 73.57 (d), 72.49 (d), 71.12 (d), 69.89 (d), 65.79 (t), 53.49 (d), 46.82 (s), 40.54 (d), 39.79 (d), 39.52 (s), 36.17 (t), 32.45 (q), 32.41 (t), 26.81 (t), 26.01 (q), 21.37, 21.07, 20.96, 20.86 (4xq, 4xAc), 16.11 (q), 12.98 (q), 6.71 (q), 4.54 (t). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3645.

4a: a colorless amorphous solid, [α]_D²⁵ +60.1° (c 0.90, CHCl₃). ¹H NMR δ_H 6.24 (d, 1H, $J=10.7$ Hz, H-10), 5.84 (d, 1H, $J=10.7$ Hz, H-9), 5.70 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.67 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 3.63 (dd, 1H, $J=10.2, 2.5$ Hz, H-20), 3.42 (m, 1H, H-5), 3.17 (dd, 1H, $J=5.5, 4.8$ Hz, H-3), 3.10 (dd, 1H, $J=10.2, 3.5$ Hz, H-20), 2.79 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.19 (m, 1H, H-4), 2.18 (s, 3H, H₃-18), 2.07 (s, 3H, Ac), 2.06 (s, 3H, Ac), 2.01 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.97 (m, 1H, H-6), 1.90 (m, 1H, H-2), 1.77 (m, 1H, H-1), 1.70-1.69 (m, 2H, H-6, H-2), 1.57 (s, 3H, H₃-16), 1.10 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.06 (s, 3H, H₃-17), 0.88 (s, 9H, 3CH₃), 0.84 (s, 3H, H₃-19), 0.05 (s, 3H, CH₃), 0.04 (s, 3H, CH₃). ¹³C NMR δ_c 170.47, 170.05, 169.89, 169.41 (4xs, 4xAc), 139.27 (s), 136.40 (s), 76.80 (d), 73.26 (d), 72.17 (d), 71.59 (d), 69.82 (d), 66.71 (t), 50.04, (d), 46.19 (s), 40.11 (d), 39.91 (d), 39.45 (s), 36.15 (t), 32.41 (t), 32.17 (q), 26.84 (t), 25.94 (q), 25.90 (q), 25.89 (q), 25.88 (q), 21.84, 21.56, 20.90, 20.78 (4xq, 4xAc), 17.92 (s), 16.12 (q), 12.94 (q), -3.32 (q), -3.21 (q). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3633. **4b**: a colorless amorphous solid, [α]_D²⁵ +96.4° (c 0.14, CHCl₃). ¹H NMR δ_H 6.23 (d, 1H, $J=10.8$ Hz, H-10), 5.84 (d, 1H, $J=10.8$ Hz, H-9), 5.70 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.66 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 3.86 (dd, 1H, $J=10.3, 2.1$ Hz, H-20), 3.52 (dd, 1H, $J=10.3, 4.8$ Hz, H-20), 3.51 (m, 1H, H-5), 3.04 (dd, 1H, $J=10.0, 5.4$ Hz, H-3), 2.78 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.18 (s, 3H, H₃-18), 2.13 (m, 1H, H-4), 2.08 (s, 3H, Ac), 2.05 (s, 3H, Ac), 2.00 (s, 3H, Ac), 1.98 (s+m, 4H, Ac+H-6), 1.86 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.71 (m, 1H, H-2), 1.67 (m, 1H, H-6), 1.58 (s, 3H, H₃-16), 1.09 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.05 (s, 3H, H₃-17), 0.89 (s, 9H, 3CH₃), 0.85 (s, 3H, H₃-19), 0.05 (s, 3H, CH₃), 0.04 (s, 3H, CH₃). ¹³C NMR δ_c 170.56, 170.07, 169.90, 169.34 (4xs, 4xAc), 138.81 (s), 135.94 (s), 76.91 (d), 74.01 (d), 72.37 (d), 70.58 (d), 69.89 (d), 65.29 (t), 53.41 (d), 45.94 (s), 39.98 (d), 39.87 (d), 38.94 (s), 36.21 (t),

32.19 (t), 32.15(q), 26.79 (t), 26.01 (q), 25.91 (q), 25.90 (q), 25.88 (q), 21.45, 21.10, 20.86, 20.42 (4×q, 4×Ac), 17.94 (s), 15.98 (q), 13.02 (q), -3.21 (q), -3.17 (q). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3641.

5a: a colorless amorphous solid, $[\alpha]_D^{25} +102.3^\circ$ (c 0.31, CHCl₃). ¹H NMR δ_H 6.07 (d, 1H, *J* =10.4 Hz, H-10), 5.76 (dd, 1H, *J* =10.4, 5.0 Hz, H-9), 5.72 (d, 1H, *J* =10.4 Hz, H-13), 5.62 (dd, 1H, *J* =6.0, 2.3 Hz, H-2), 4.76 (m, 1H, H-5), 3.67 (dd, 1H, *J* =10.2, 2.5 Hz, H-20), 3.20 (dd, 1H, *J* =6.0, 4.5 Hz, H-3), 3.14 (dd, 1H, *J* =10.2, 3.5 Hz, H-20), 2.68 (ddd, 1H, *J* =15.7, 10.4, 8.6Hz, H-14), 2.13 (s, 3H, Ac), 2.11 (s, 3H, H₃-18), 2.08 (s, 3H, Ac), 2.03 (s, 3H, Ac), 2.00 (s, 3H, Ac), 1.99 (s, 3H, Ac), 1.98 (dd, 1H, *J* =8.6, 2.3 Hz, H-1), 1.89 (m, 1H, H-7), 1.79 (m, 1H, H-6), 1.64 (s, 3H, H₃-16), 1.60 (m, 2H, H-7, H-6), 1.45 (dd, 1H, *J* =15.7, 5.0 Hz, H-14), 1.05 (s, 3H, H₃-17), 0.89 (s, 3H, H₃-19). ¹³C NMR δ_C 170.67, 170.34, 169.98, 169.88, 169.34 (5×s, 5×Ac), 140.01 (s), 136.59 (s), 75.82 (d), 73.62 (d), 72.84 (d), 71.68 (d), 69.89 (d), 65.13 (t), 51.27 (d), 45.64 (s), 40.10 (d), 40.01 (d), 39.21 (s), 32.21 (t), 32.17 (q), 28.18 (t), 27.46 (t), 25.98 (q), 21.65, 21.43, 21.07, 20.92, 20.34 (5×q, 5×Ac), 15.94 (q), 12.32 (q). HMRS (FAB) calcd for C₃₀H₄₅O₁₁ (M⁺+1) 518.2959, found 518.2954.

6a: a colorless amorphous solid, $[\alpha]_D^{23} +93.5^\circ$ (c 0.64, CHCl₃). ¹H NMR δ_H 6.08 (d, 1H, *J* =10.4 Hz, H-10), 5.75 (dd, 1H, *J* =10.4, 5.0 Hz, H-9), 5.72 (d, 1H, *J* =10.4 Hz, H-13), 5.61 (dd, 1H, *J* =6.1, 2.2 Hz, H-2), 3.65 (dd, 1H, *J* =10.2, 2.5 Hz, H-20), 3.36 (m, 1H, H-5), 3.17 (dd, 1H, *J* =6.1, 4.5 Hz, H-3), 3.10 (dd, 1H, *J* =10.2, 3.5 Hz, H-20), 2.67 (ddd, 1H, *J* =15.7, 10.4, 8.5 Hz, H-14), 2.12 (s, 3H, H₃-18), 2.08 (s, 3H, Ac), 2.04 (s, 3H, Ac), 2.00 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.97 (dd, 1H, *J* =8.5, 2.2 Hz, H-1), 1.90 (m, 1H, H-7), 1.80 (m, 1H, H-6), 1.64 (s, 3H, H₃-16), 1.61-1.59 (m, 2H, H-7, H-6), 1.44 (dd, 1H, *J* =15.7, 5.0 Hz, H-14), 1.06 (s, 3H, H₃-17), 0.98 (t, 9H, *J* =7.0 Hz, 3CH₃), 0.90 (s, 3H, H₃-19), 0.61 (q, 6H, *J* =7.0 Hz, 3CH₃). ¹³C NMR δ_C 170.41, 170.00, 169.92, 169.36 (4×s, 4×Ac), 139.89 (s), 136.56 (s), 75.67 (d), 73.45 (d), 72.89 (d), 71.09 (d), 69.70 (d), 66.37 (t), 51.21 (d), 45.72 (s), 40.17 (d), 40.13 (d), 38.91 (s), 33.41 (q), 32.84 (t), 28.46 (t), 27.56 (t), 25.97 (q), 21.44, 21.06, 20.87, 20.40 (4×q, 4×Ac), 16.17 (q), 13.12 (q), 6.76 (q), 4.36 (t). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3646.

Preparation of 1-deoxy-2-debenzoyloxy-4-deacetoxybaccatin VI (9) from compound (3a)

A solution of **3a** (163 mg, 0.25 mmol) in THF (2 mL) was added tetrabutylammonium fluoride in THF (1.0M, 1 mL). The reaction mixture was stirred for 1 h at rt. Ethyl acetate (20 mL) was added and the organic layers were washed with saturated aqueous NaHCO₃, and dried over MgSO₄. After evaporation of the solvent under reduced pressure, the residue was used for next step reaction without further purification.

A solution of imidazole (245 mg, 3.6 mmol) and *tert*-butyldimethylsilyl chloride (226 mg, 1.5 mmol) in dry DMF (2 mL) was stirred for 15 min at rt followed by an addition of the above residue in dry DMF (1 mL). The resulting reaction mixture was stirred for an additional 3 h, diluted with a solution of 10% aqueous citric acid (10 mL), and extracted with ethyl acetate. The organic layer was washed with brine, dried over MgSO₄, and evaporated under reduced pressure. The residue was purified by chromatography on silica gel

(ethyl acetate:hexane=1:2 v/v) to give 132 mg (81%) of **7** as an oil. ^1H nmr δ_{H} 6.23 (d, 1H, $J=10.8$ Hz, H-10), 5.84 (d, 1H, $J=10.8$ Hz, H-9), 5.71 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.66 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 4.15 (dd, 1H, $J=10.5, 2.1$ Hz, H-20), 3.58 (m, 1H, H-5), 3.54 (dd, 1H, $J=10.5, 3.5$ Hz, H-20), 2.76 (ddd, 1H, $J=15.6, 10.2, 8.5$ Hz, H-14), 2.67 (dd, 1H, $J=5.5, 4.5$ Hz, H-3), 2.20 (m, 1H, H-4), 2.17 (s, 3H, H₃-18), 2.08 (s, 3H, Ac), 2.06 (s, 3H, Ac), 20.1 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.97 (m, 1H, H-6), 1.89 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.70 (m, 2H, H-2, H-6), 1.58 (s, 3H, H₃-16), 1.09 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.07 (s, 3H, H₃-17), 0.87 (s, 9H, 3CH₃), 0.84 (s, 3H, H₃-19), 0.05 (s, 3H, CH₃), 0.04 (s, 3H, CH₃). HMRS (EI) calcd for C₃₄H₅₆O₁₀Si (M⁺) 652.3639, found 652.3645.

A solution of **7** (130 mg, 0.2 mmol) in pyridine (2 mL) at 0°C was added MsCl (0.1 mL). The reaction mixture was stirred for 20 h at rt and CH₂Cl₂ (15 mL) was added. The resulting solution was washed with a solution of 10% aqueous citric acid (7 mL), saturated aqueous NaHCO₃, and dried over MgSO₄. After removal of the solvent under reduced pressure, the residue was chromatographed on silics gel (ethyl acetate:hexane =1:2 v/v) to give 108 mg (74%) of **8** as an oil. ^1H NMR δ_{H} 6.24 (d, 1H, $J=10.8$ Hz, H-10), 5.84 (d, 1H, $J=10.8$ Hz, H-9), 5.71 (dd, 1H, $J=10.3, 4.5$ Hz, H-13), 5.64 (dd, 1H, $J=11.6, 5.4$ Hz, H-7), 4.84 (m, 1H, H-5), 4.17 (dd, 1H, $J=10.5, 2.1$ Hz, H-20), 3.56 (dd, 1H, $J=10.5, 3.5$ Hz, H-20), 2.97 (s, 3H, CH₃), 2.78 (ddd, 1H, $J=15.6, 10.2, 8.5$ Hz, H-14), 2.66 (dd, 1H, $J=5.5, 4.5$ Hz, H-3), 2.20 (m, 1H, H-4), 2.18 (s, 3H, H₃-18), 2.08 (s, 3H, Ac), 2.06 (s, 3H, Ac), 2.01 (m, H-6), 2.00 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.90 (m, 1H, H-2), 1.78 (m, 1H, H-1), 1.70-1.69 (m, 2H, H-2, H-6), 1.54 (s, 3H, H₃-16), 1.10 (dd, 1H, $J=15.6, 4.5$ Hz, H-14), 1.07 (s, 3H, H₃-17), 0.85 (s, 9H, 3CH₃), 0.83 (s, 3H, H₃-19), 0.05 (s, 3H, CH₃), 0.03 (s, 3H, CH₃). HMRS (FAB) calcd for C₃₅H₅₈O₁₂NaSSi (M⁺+Na) 753.3312, found 753.3317.

A solution of **8** (73 mg, 0.1 mmol) in THF (1.5 mL) was added tetrabutylammonium fluoride in THF (1.0M, 0.7 mL). The reaction mixture was stirred for 1 h at rt. Ethyl acetate (10 mL) was added and the organic layers were washed with saturated aqueous NaHCO₃ and dried over MgSO₄. After evaporation of the solvent under reduced pressure, the residue was dissolved in butanone (2 mL) and then tetrabutylammonium acetate (270 mg, 0.9 mmol) was added. The resulting mixture was refluxed for 20 h and diluted with ethyl acetate (10 mL). The resulting solution was washed with saturated aqueous NH₄Cl, dried over MgSO₄, and evaporated under reduced pressure. The residue was chromatographed on silics gel (ethyl acetate:hexane =1:2 v/v) to give 31 mg (61%) of **9** as a colorless oil. $[\alpha]_{\text{D}}^{25} +83.2^\circ$ (c 0.03, CHCl₃). ^1H NMR δ_{H} 6.21 (d, 1H, $J=10.7$ Hz, H-10), 5.86 (d, 1H, $J=10.7$ Hz, H-9), 5.72 (dd, 1H, $J=10.3, 5.0$ Hz, H-13), 5.68 (dd, 1H, $J=11.6, 5.0$ Hz, H-7), 5.20 (m, 1H, H-5), 4.35 (d, 1H, $J=8.1$ Hz, H-20), 4.27 (d, 1H, $J=8.1$ Hz, H-20), 3.82 (m, 1H, H-4), 3.27 (dd, 1H, $J=6.0, 5.7$ Hz, H-3), 2.79 (ddd, 1H, $J=15.6, 10.3, 8.5$ Hz, H-14), 2.48 (m, 1H, H-6), 2.17 (s, 3H, H₃-18), 2.09 (s, 3H, Ac), 2.08 (m, 1H, H-6), 2.07 (s, 3H, Ac), 2.03 (s, 3H, Ac), 1.98 (s, 3H, Ac), 1.89 (m, 1H, H-2), 1.80 (m, 1H, H-1), 1.72 (m, 1H, H-2), 1.57 (s, 3H, H₃-16), 1.12 (dd, 1H, $J=15.6, 5.0$ Hz, H-14), 1.05 (s, 3H, H₃-17), 0.87 (s, 3H, H₃-19). ^{13}C NMR δ_{C} 170.61, 170.01, 169.94, 169.32 (4xs, 4xAc), 139.68 (s), 136.24 (s), 82.56 (d), 77.64 (d), 74.68 (t), 72.57 (d), 71.62 (d), 70.89 (d), 56.27 (d), 45.14 (s), 41.15 (d), 39.87 (d), 39.41 (s), 37.68 (t), 33.07 (q), 32.56 (t), 26.96 (t), 25.89 (q), 21.32, 21.26, 20.91, 20.24 (4xq, 4xAc), 16.12 (q), 14.17 (q). HMRS (EI) calcd for C₂₈H₄₀O₉ (M⁺) 520.2670, found 520.2677.

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