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SYNTHESIS OF INDOLIZIDINE 167B

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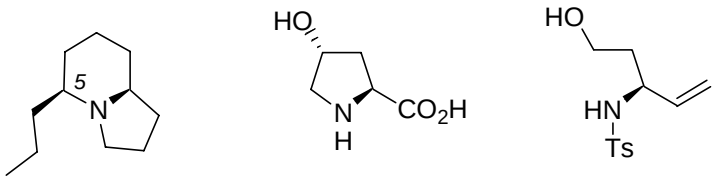
Abstract – A new synthesis of indolizidine 167B has been achieved from *trans*-(2*S*,4*R*)-4-hydroxyproline via ring-closing metathesis as the key step.

The structural framework of *trans*-(2*S*,4*R*)-4-hydroxyproline possesses three functional groups that can be easily modified.[1] Recently, we have introduced a straightforward approach for the syntheses of anisomycin,[2a] epibatidine,[2b] pancracine,[2c] streptorubin B,[2d] statine,[2e] vigabatrin®,[2f] DMJ analogs,[2g] diarylmethyl-1*H*-pyrrole,[2h] pipecolic acid and baikiain[2i] employing *trans*-(2*S*,4*R*)-4-hydroxyproline as the starting material. To explore a new application, synthetic studies toward indolizidine 167B were further investigated.

The indolizidine alkaloid 167B was detected once as a very minor trace component in unidentified dendrobatidae frogs found in a single population.[3] Indolizidine 167B with a single propyl substitutent at C-5 of the indolizidine ring is the simplest bicyclic gephyotoxin alkaloid (see Figure 1). Various methods for the asymmetric synthesis of indolizidine 167B mainly based on auxiliary-supported or chiral pool approaches have been reported in the literature.[4] In connection with our studies on *trans*-(2*S*,4*R*)-4-hydroxyproline (**2**) as the chiral material, we are interested in developing a new method to indolizidine 167B (**1**) via the ring-closing metathesis.

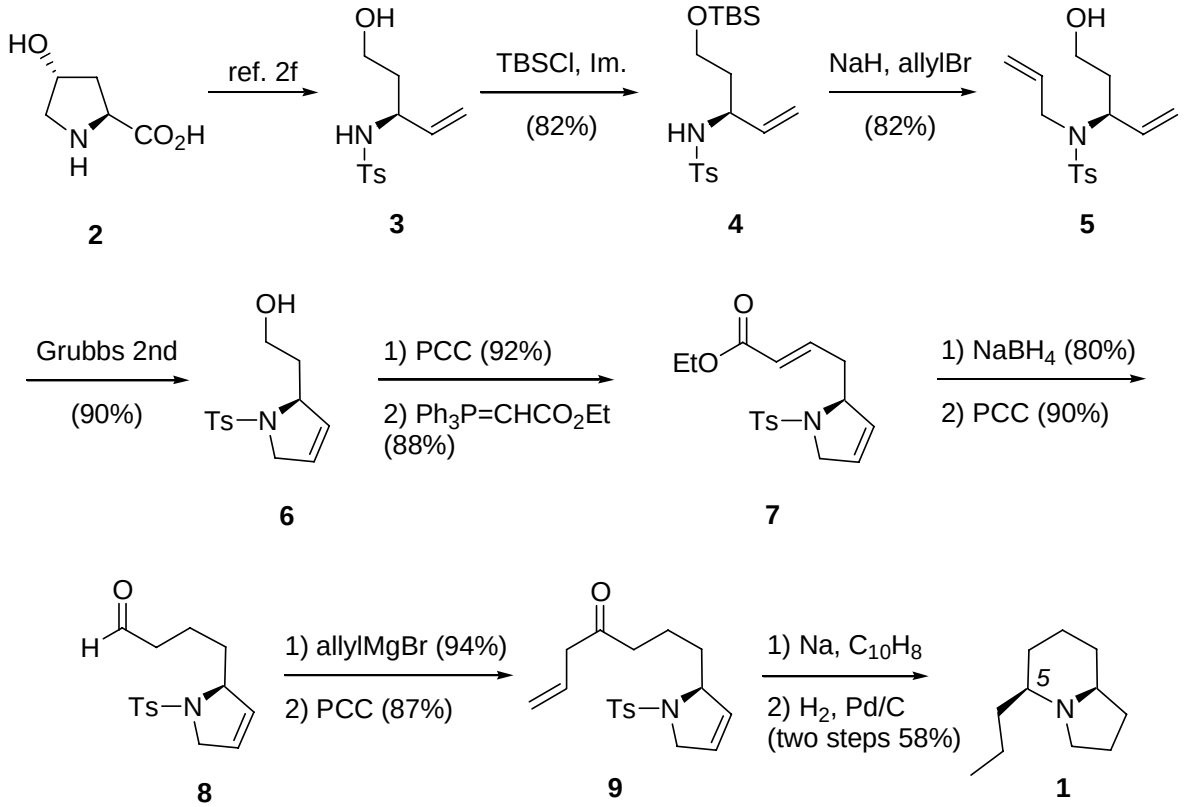


indolizidine 167 B (**1**) **2** **3**

Figure 1. Structures of indolizidine 167B (**1**), *trans*-(2*S*,4*R*)-4-hydroxyproline (**2**), and aminoalcohol (**3**)

As shown in Scheme 1, we studied the approach to indolizidine 167B (**1**) from aminoalcohol (**3**), which was prepared from *trans*-(2*S*,4*R*)-4-hydroxyproline (**2**) by our preliminary report.[2f] Compound (**5**) was

synthesized via silylation of compound (**3**) and *N*-allylation of the resultant product (**4**). The silyl group was also removed under the condition. To build up the pyrrolidine skeleton, diene (**5**) was subjected to a ring-closing metathesis employing Grubbs' 2nd catalyst, the expected pyrrolidine ring (**6**) was generated.[5] When treatment of alcohol (**6**) with pyridinium chlorochromate and Wittig olefination with ethyl triphenylphosphoranylidene acetate, the sole (*E*)-α,β-unsaturated ester (**7**) was afforded. With **7** in hand, ester (**7**) was further transformed to aldehyde (**8**) by 1,4-reduction and subsequent PCC-mediated oxidation under the standard conditions. The key ketone (**9**) was furnished by the chain elongation of aldehyde (**8**) via Grignard addition with allylmagnesium bromide and followed by PCC-mediated oxidation.



Scheme 1. Synthesis of indolizidine 167B (**1**)

Finally, synthesis of indolizidine 167B (**1**) was accomplished via desulfonation with sodium naphthalenide and hydrogenation with hydrogen in the presence of a catalytic amount of 10% palladium on activated carbon.[4f] In summary, we succeeded in accomplishing the synthesis of indolizidine 167B (**1**) from *trans*-(2*S*,4*R*)-4-hydroxyproline (**2**) via the ring-closing metathesis as the key step. Currently studies are in progress in this direction.

EXPERIMENTAL

General. Tetrahydrofuran (THF) was distilled prior to use from a deep-blue solution of sodium-benzophenone ketyl. All other reagents were obtained from commercial sources and used without

further purification. Reaction was routinely carried out under an atmosphere of dry nitrogen with magnetic stirring. Crude product was purified using column chromatography on SiO_2 (MN Kieselgel 60, 70~230 mesh).

[1-(2-*t*-Butyldimethylsilyloxyethyl)allyl]-4-methylbenzenesulfonamide (4).

t-Butyldimethylsilyl chloride (150 mg, 1.0 mmol) and imidazole (136 mg, 2.0 mmol) were added to a stirred solution of compound (**3**) (150 mg, 0.59 mmol) in DMF (3 mL) at rt. The reaction mixture was stirred at rt for 2 h. The reaction mixture was concentrated. The residue was diluted with water (10 mL) and the mixture was extracted with AcOEt (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to yield crude product. Purification on silica gel (hexane/AcOEt = 5/1) afforded silyl product (**4**) (178 mg, 82%) as an oil. $[\alpha]^{25}_{D}$ -3.3^{o} (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 3480, 3277, 2927, 1646, 1326, 1158, 1093 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{18}H_{32}NO_3SSi$ (M^++1) 370.1872, found 370.1866; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.74 (d, *J* = 8.0 Hz, 2H), 7.27 (d, *J* = 8.0 Hz, 2H), 5.72 (d, *J* = 6.5 Hz, 1H), 5.68-5.62 (m, 1H), 5.17 (d, *J* = 17.5 Hz, 1H), 5.07 (d, *J* = 10.0 Hz, 1H), 3.98-3.93 (m, 1H), 3.74-3.69 (m, 1H), 3.60-3.56 (m, 1H), 2.42 (s, 3H), 1.71-1.58 (m, 2H), 0.91 (s, 9H), 0.52 (s, 3H), 0.49 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 142.95, 138.14, 137.43, 129.43 (2x), 127.23 (2x), 116.13, 60.33, 55.23, 36.40, 25.83 (3x), 21.50, 18.06, -5.57, -5.61; Anal. Calcd for $C_{18}H_{31}NO_3SSi$: C, 58.49; H, 8.45; N, 3.79. Found: C, 58.27; H, 8.61; N, 3.92.

***N*-Allyl-*N*-[1-(2-*t*-butyldimethylsilyloxyethyl)allyl]-4-methylbenzenesulfonamide (5).**

A solution of compound **(4)** (150 mg, 0.40 mmol) in DMF (2 mL) was added to a rapidly stirred suspension of sodium hydride (60%, 100 mg, 2.5 mmol) in DMF (3 mL). After the reaction mixture was stirred at 0 ^{o}C for 5 min, allyl bromide (100 mg, 0.82 mmol) was added at 0 ^{o}C. The resulting mixture was stirred at rt for 3 h. The reaction was quenched with $NH_4Cl_{(aq)}$ solution (15%, 1 mL) and the mixture was concentrated. The residue was diluted with water (10 mL) and the mixture was extracted with EtOAc (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to yield crude product. Purification on silica gel (hexane/EtOAc = 4/1) afforded compound (**5**) (100 mg, 82%) as an oil. $[\alpha]^{25}_{D}$ -17.2^{o} (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 3445, 2923, 2862, 1641, 1330, 1158, 1090, 928, 663 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{15}H_{22}NO_3S$ (M^++1) 296.1320, found 296.1325; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.72 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 5.91-5.83 (m, 1H), 5.44-5.37 (m, 1H), 5.16 (d, *J* = 17.5 Hz, 1H), 5.10 (d, *J* = 10.0 Hz, 1H), 5.06 (d, *J* = 10.0 Hz, 1H), 4.97 (d, *J* = 17.5 Hz, 1H), 4.59-4.54 (m, 1H), 3.95-3.87 (m, 2H), 3.67 (dt, *J* = 4.5, 11.5 Hz, 1H), 3.59 (dd, *J* = 8.0, 16.0 Hz, 1H), 2.76 (br s, 1H), 2.44 (s, 3H), 1.89-1.82 (m, 1H), 1.76-1.70 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.45, 137.54, 135.89, 135.56, 129.72 (2x), 127.06 (2x), 118.12, 117.69, 58.02, 55.90, 47.00, 33.98, 21.52; Anal. Calcd for $C_{15}H_{21}NO_3S$: C, 60.99; H, 7.17; N, 4.74. Found: C, 61.13; H, 7.52; N, 5.03.

2-[1-(4-Methylphenylsulfonyl)-2,5-dihydro-1*H*-pyrrol-2-yl]ethanol (6).

Grubbs' 2nd catalyst (17 mg, 0.02 mmol) was added to a solution of compound (**5**) (120 mg, 0.41 mmol) in CH_2Cl_2 (10 mL) and the reaction mixture was refluxed under nitrogen atmosphere for 12 h. The mixture was concentrated and purified by flash column chromatography (hexane/EtOAc = 4/1) to yield compound (**6**) (98 mg, 90%) as a colorless solid. mp 80-81 ^oC; $[\alpha]^{26}_D$ +42.5^o (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 3446, 1636, 1332, 1160, 1090, 666 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{13}H_{18}NO_3S$ (M^++1) 268.1007, found 268.1010; ^1H NMR (500 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.5 Hz, 2H), 7.30 (d, *J* = 8.5 Hz, 2H), 5.63-5.61 (m, 1H), 5.57-5.55 (m, 1H), 4.70-4.67 (m, 1H), 4.13-4.11 (m, 2H), 4.01-3.96 (m, 1H), 3.75 (dt, *J* = 5.0, 12.0 Hz, 1H), 2.42 (s, 3H), 1.99-1.92 (m, 1H), 1.74-1.68 (m, 1H), 1.65 (br s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.75, 133.99, 130.53, 129.74 (2x), 127.52 (2x), 124.69, 64.69, 58.97, 55.24, 38.71, 21.53; Anal. Calcd for $C_{13}H_{17}NO_3S$: C, 58.40; H, 6.41; N, 5.24. Found: C, 58.79; H, 6.59; N, 5.53.

4-[1-(4-Methylphenylsulfonyl)-2,5-dihydro-1*H*-pyrrol-2-yl]but-2-enoic acid ethyl ester (7).

A solution of compound (**6**) (92 mg, 0.34 mmol) in CH_2Cl_2 (20 mL) was added to a stirred mixture of pyridinium chlorochromate (431 mg, 2.0 mmol) and Celite (1.0 g) in CH_2Cl_2 (20 mL). After being stirred at rt for 6 h, the mixture was filtered through a short silica gel column. The filtrate was dried, filtered and evaporated to yield crude compound. Purification on silica gel (hexane/EtOAc = 8/1) afforded aldehyde (84 mg, 92%) as an oil. $[\alpha]^{25}_D$ -87.2^o (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 2956, 2850, 2722, 1718, 1340, 1160 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{13}H_{16}NO_3S$ (M^++1) 266.0851, found 266.0855; ^1H NMR (500 MHz, $CDCl_3$) δ 9.82 (d, *J* = 1.0 Hz, 1H), 7.71 (d, *J* = 8.0 Hz, 2H), 7.33 (d, *J* = 8.0 Hz, 2H), 5.69-5.64 (m, 2H), 4.83-4.78 (m, 1H), 4.17 (dt, *J* = 2.0, 5.5, 15.5 Hz, 1H), 4.09-4.05 (m, 1H), 3.22 (ddd, *J* = 1.5, 4.0, 18.0 Hz, 1H), 2.85 (ddd, *J* = 1.0, 8.5, 18.0 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 200.47, 143.85, 133.78, 129.89 (2x), 129.12, 127.52 (2x), 125.47, 62.14, 55.37, 50.72, 21.53; Anal. Calcd for $C_{13}H_{15}NO_3S$: C, 58.85; H, 5.70; N, 5.28. Found: C, 58.53; H, 5.93; N, 5.60. A solution of aldehyde (124 mg, 0.47 mmol) in CH_2Cl_2 (10 mL) was added to a rapidly stirred solution of $Ph_3P{=}CHCO_2Et$ (348 mg, 1.0 mmol) in CH_2Cl_2 (10 mL). After the reaction mixture was stirred at rt for 2 h, the resulting mixture was concentrated. The residue was diluted with water (10 mL) and extracted with EtOAc (3 x 30 mL). The combined organic layers were washed with brine, dried, filtered, evaporated to yield crude compound. Purification on silica gel (hexane/EtOAc = 10/1) afforded compound (**7**) (138 mg, 88%) as an oil. $[\alpha]^{25}_D$ +45.6^o (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 2954, 1647, 1155 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{17}H_{22}NO_4S$ (M^++1) 336.1270, found 336.1272; ^1H NMR (500 MHz, $CDCl_3$) δ 7.71 (d, *J* = 8.0 Hz, 2H), 7.31 (d, *J* = 8.0 Hz, 2H), 6.88 (dt, *J* = 2.5, 16.0 Hz, 1H), 5.88 (d, *J* = 16.0 Hz, 1H), 5.68-5.66 (m, 1H), 5.57-5.55 (m, 1H), 4.58 (br s, 1H), 4.17 (q, *J* = 7.0 Hz, 2H), 4.13-4.10 (m, 2H), 2.78-2.74 (m, 1H), 2.71-2.65 (m, 1H), 2.43 (s, 3H), 1.29 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.19, 143.64, 143.29, 134.47,

129.79 (2x), 128.56, 127.40 (2x), 125.88, 124.51, 65.96, 60.29, 55.75, 39.00, 21.52, 14.24; Anal. Calcd for $C_{17}H_{21}NO_4S$: C, 60.87; H, 6.31; N, 4.18. Found: C, 60.69; H, 6.59; N, 4.51.

4-[1-(4-Methylphenylsulfonyl)-2,5-dihydro-1*H*-pyrrol-2-yl]butyraldehyde (8).

Sodium borohydride (32 mg, 0.87 mmol) was added to a solution of compound (**7**) (118 mg, 0.35 mmol) in MeOH (15 mL) was stirred at ice bath, and The mixture was stirred for 5 h at rt. Saturated $NaHCO_{3(aq)}$ solution (1 mL) was added to the reaction mixture and concentrated. The residue was diluted with water (10 mL) and extracted with EtOAc (3 x 30 mL). The combined organic layers were washed with brine, dried, filtered, evaporated to yield crude compound. Purification on silica gel (hexane/EtOAc = 4/1) afforded alcohol (83 mg, 80%) as an oil. $[\alpha]^{25}_D$ +79.4^o (*c* 0.01, $CHCl_3$); IR ($CHCl_3$) 3448, 2919, 1636, 1161 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{15}H_{22}NO_3S$ (M^++1) 296.1320, found 296.1325; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 5.61-5.56 (m, 2H), 4.49 (br s, 1H), 4.13-4.10 (m, 2H), 3.66 (t, *J* = 6.5 Hz, 2H), 2.42 (s, 3H), 1.82-1.78 (m, 2H), 1.63-1.55 (m, 3H), 1.51-1.34 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.36, 134.72, 129.67 (2x), 129.64, 127.39 (2x), 124.82, 67.14, 62.77, 55.68, 35.65, 32.58, 21.51, 20.61. A solution of alcohol (76 mg, 0.26 mmol) in CH_2Cl_2 (10 mL) was added to a stirred mixture of pyridinium chlorochromate (216 mg, 1.0 mmol) and Celite (0.5 g) in CH_2Cl_2 (15 mL). After being stirred at rt for 6 h, the mixture was filtered through a short silica gel column. The filtrate was dried, filtered and evaporated to yield crude compound. Purification on silica gel (hexane/EtOAc = 8/1) afforded compound (**8**) (68 mg, 90%) as an oil. $[\alpha]^{24}_D$ +9.2^o (*c* 0.01, $CHCl_3$); HRMS (ESI) *m*/*z* calcd for $C_{15}H_{20}NO_3S$ (M^++1) 294.1164, found 294.1162; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.78 (t, *J* = 1.5 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 2H), 7.31 (d, *J* = 8.0 Hz, 2H), 5.65-5.63 (m, 1H), 5.57-5.55 (m, 1H), 4.45-4.49 (m, 1H), 4.17-4.06 (m, 2H), 2.52-2.48 (m, 2H), 2.42 (m, 3H), 1.82-1.52 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 202.30, 143.49, 134.50, 129.73 (2x), 129.29, 127.41 (2x), 125.22, 66.86, 55.76, 43.78, 35.11, 21.52, 16.84; Anal. Calcd for $C_{15}H_{19}NO_3S$: C, 61.41; H, 6.53; N, 4.77. Found: C, 61.60; H, 6.38; N, 4.92.

7-[1-(4-Methylphenylsulfonyl)-2,5-dihydro-1*H*-pyrrol-2-yl]hept-1-en-4-one (9).

A solution of allylmagnesium bromide (1.0 M in THF, 1.0 mL, 1.0 mmol) was added to a stirred solution of compound (**8**) (60 mg, 0.2 mmol) in THF (10 mL) at -78 ^{o}C. The reaction mixture was stirred at 0 ^{o}C for 2 h. The reaction was quenched with $NH_4Cl_{(aq)}$ solution (15%, 1 mL) and the mixture was concentrated. The residue was diluted with water (10 mL) and the mixture was extracted with EtOAc (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to yield crude product. Purification on silica gel (hexane/EtOAc = 4/1) afforded two alcohols (65 mg, 94%) as an oil. IR ($CHCl_3$) 3421, 2917, 1637, 1339, 1166, 1092 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{18}H_{26}NO_3S$ (M^++1) 336.1633, found 336.1636; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.5 Hz, 2H), 7.30 (d, *J* =

8.5 Hz, 2H), 5.87-5.79 (m, 1H), 5.63-5.56 (m, 2H), 5.16-5.13 (m, 2H), 4.49-4.48 (m, 1H), 4.16-4.08 (m, 2H), 3.68-3.62 (m, 1H), 2.42 (s, 3H), 2.32-2.27 (m, 1H), 2.18-2.12 (m, 1H), 1.84-1.74 (m, 2H), 1.58 (br s, 1H), 1.55-1.43 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 143.34, 134.79, 129.66 (2x), 129.64, 127.49, 127.39 (2x), 124.80, 118.19, 70.47 (1/2C), 70.44 (1/2C), 67.20 (1/2C), 67.12 (1/2C), 55.71 (1/2C), 55.64 (1/2C), 42.09 (1/2C), 41.94 (1/2C), 36.64 (1/2C), 36.61 (1/2C), 35.97 (1/2C), 35.81 (1/2C), 21.51, 20.61 (1/2C), 20.54 (1/2C). A solution of alcohol (58 mg, 0.17 mmol) in CH_2Cl_2 (10 mL) was added to a stirred mixture of pyridinium chlorochromate (108 mg, 0.5 mmol) and Celite (0.3 g) in CH_2Cl_2 (15 mL). After being stirred at rt for 6 h, the mixture was filtered through a short silica gel column. The filtrate was dried, filtered and evaporated to yield crude compound. Purification on silica gel (hexane/EtOAc = 6/1) afforded compound (**9**) (50 mg, 87%) as an oil. $[\alpha]^{24}_D$ +18.2^o (*c* 0.01, $CHCl_3$); HRMS (ESI) *m*/*z* calcd for $C_{18}H_{24}NO_3S$ (M^++1) 334.1477, found 334.1479; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 5.96-5.88 (m, 1H), 5.63-5.61 (m, 1H), 5.58-5.56 (m, 1H), 5.21-5.13 (m, 2H), 4.47-4.45 (m, 1H), 4.16-4.06 (m, 2H), 3.18 (d, *J* = 7.0 Hz, 2H), 2.50 (dd, *J* = 6.5, 14.0 Hz, 2H), 2.42 (s, 3H), 1.79-1.74 (m, 2H), 1.67-1.55 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 208.58, 143.42, 134.54, 130.57, 129.70 (2x), 129.39, 127.40 (2x), 125.02, 118.85, 66.99, 55.74, 47.78, 42.07, 35.25, 21.52, 18.40.

Indolizidine 167B (5-Propyloctahydroindolizine, 1).

A freshly prepared solution of sodium naphthalenide (1.0 M in THF, 2 mL, 2.0 mmol) was added to a solution of compound (**9**) (48 mg, 0.15 mmol) in THF (10 mL) at 0 ^{o}C for 2h. Water (1 mL) was poured into the reaction mixture and evaporated to afford the residue. Water (10 mL) was poured into the residue and extracted with Et_2O (3 x 20 mL). The combined organic layers were washed with brine, dried, filtered and evaporated to yield the crude product. Without further purification, 10% palladium on activated carbon (10 mg) was added to the solution of the resulting amine in MeOH (10 mL). Then hydrogen was bubbled into the mixture for 10 min, and the reaction mixture was continued to stir for 3 h at rt. The catalyst was filtered through a short plug of Celite and washing with MeOH (2 x 10 mL). The combined organic layers were evaporated to yield crude compound. Purification on silica gel (hexane/ethyl acetate = 1/2~1/3) produced compound (**1**) (14 mg, 58%) as an oil. $[\alpha]^{25}_D$ +99.4^o (*c* 0.005, $CHCl_3$) [lit.,[4g] $[\alpha]^{25}_D$ +101^o (*c* 0.44, CH_2Cl_2)]; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.31 (dt, *J* = 1.8, 6.6 Hz, 1H), 2.10-1.62 (m, 10H), 1.59-1.04 (m, 7H), 0.92 (t, *J* = 6.9 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 65.02, 63.66, 51.45, 36.78, 30.89, 30.66, 24.59, 20.33, 19.02, 14.42. ^{1}H and ^{13}CNMR spectral data was in accordance with those previously reported for this compound in the literature.[4c-d,4t]

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