Diastereoselective Ring-Rearrangement Metathesis to Set the Stereochemistry of All-carbon Quaternary Centres

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Supporting Information

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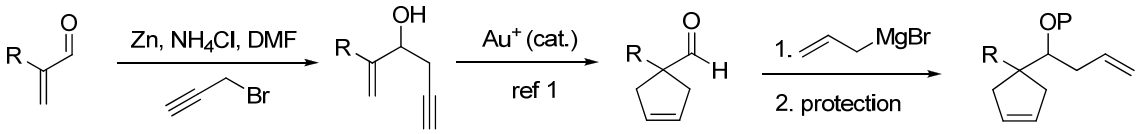
1. General Information: Reactions were carried out in oven or flame-dried glassware under a nitrogen atmosphere (balloons used for pressure equalization and exclusion of moisture) unless otherwise noted. Compounds were purchased from Aldrich or Acros or TCI America unless otherwise noted. Tetrahydrofuran (THF) and diethyl ether (Et_2O) were freshly distilled from sodium/benzophenone, and dichloromethane (DCM) was distilled from calcium hydride (CaH_2) under nitrogen atmosphere. Flash chromatography was performed using silica gel 60 Å (32–63 mesh) purchased from Silicycle Inc. Analytical thin layer chromatography (TLC) was performed on 0.25 mm E. Merck precoated silica gel 60 (particle size 0.040–0.063 mm). Yields refer to chromatographically and spectroscopically pure compounds unless otherwise stated. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker DRX-500 spectrometer. Multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), qn (quintet), sext (sextet), m (multiplet), b (broad), and app (apparent). ^{1}H NMR signals that fall within a ca. 0.3 ppm range are generally reported as a multiplet, with a single chemical shift value corresponding to the center of the peak. Coupling constants, *J*, are reported in Hz (Hertz). Electron impact (EI) mass spectra and Chemical Ionization (CI) mass spectra were obtained using a Micromass 70-VSE in the University of Illinois at Urbana-Champaign.

2. Diastereoselective ring-rearrangement metathesis

2.1. Preparation of ring-rearrangement metathesis substrates

2.1.1 Preparation of ring-rearrangement metathesis substrates 1a-h and 3a, 3d and 3f

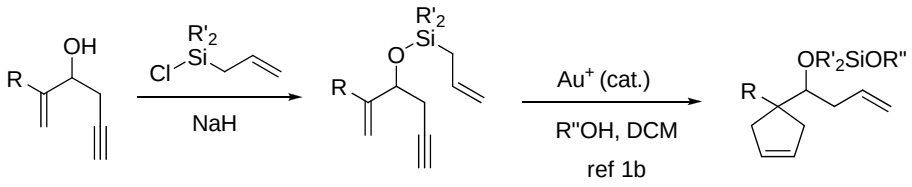


The substrates **1a-h** and **3a**, **3d** and **3f** were prepared from allylation and protection of the corresponding cyclopentyl carboaldehydes, which were synthesized according to the reported

gold catalyzed isomerization of 3-hydroxy 1,5-enynes.[1] The 3-hydroxy 1,5-enynes were prepared from Barbier-type propargylation of 2-aryl- or 2-alkyl acroleins.[1b] To a solution of carboaldehydes (1.0 mmol, 1.0 equiv.) in 5 mL of THF was added allyl magnesium bromide solution (1.2 mmol, 1.0 M, 1.2 equiv.) slowly at 0 ^{o}C. The reaction was slowly warmed up to room temperature and monitored by TLC. Upon reaction completion, saturated NH_4Cl solution was added at 0 ^{o}C to quench the reaction. Then the reaction mixture was separated and the aqueous layer was extracted by Et_2O (10 mL x 3). The extract was combined with the organic layer and then was washed with brine, dried over anhydrous $MgSO_4$, filtered, and concentrated to obtain the crude product which was purified by column chromatography to afford the pure alcohols.

To a solution of the secondary alcohols (0.5 mmol, 1.0 equiv.) and triethylamine (3.0 equiv.) in DMF (2 mL), was added *tert*-butyldimethylsilyl triflate (1.0 equiv.) and catalytic amount of *N*,*N*-dimethylaminopyridine (DMAP) at 0 ^{o}C. Then the ice bath was removed. After stirring at 80 ^{o}C for several hours, TLC showed the completion of the reaction. The mixture was quenched by saturated NH_4Cl solution and extracted with Et_2O, then dried over $MgSO_4$, concentrated under reduced pressure and purified using flash column chromatography to afford the RRM substrates **1a-h** and **3a**, **3d** and **3f.**

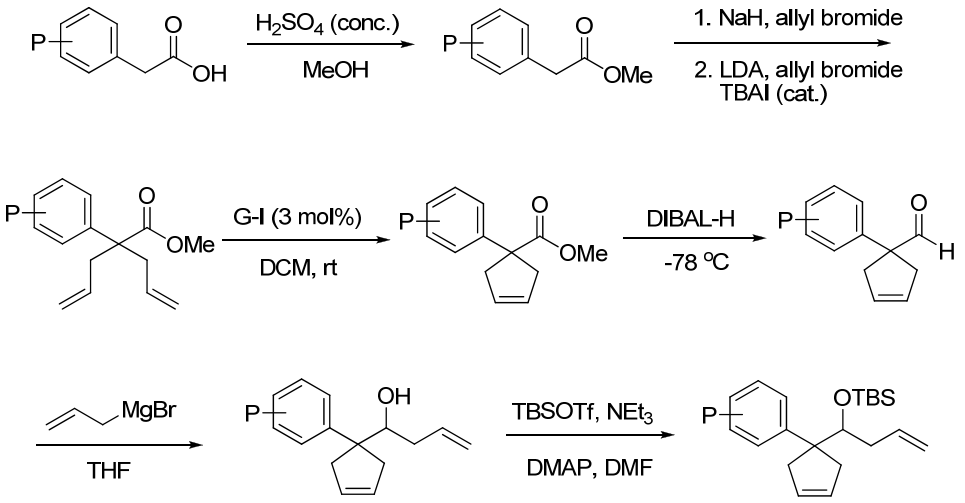
2.1.2 Preparation of ring-rearrangement metathesis substrates 3c, 3e and 3h



The substrates **3c**, **3e** and **3h** were prepared according to the reported gold catalyzed isomerization of 3-siloxy 1,5-enynes followed by intramolecular allyl trapping.[1b]

[1] (a) Kirsch, S. F.; Binder, J. T.; Crone, B.; Duschek, A.; Haug, T. T.; Liébert, C.; Menz, H. *Angew. Chem., Int. Ed.* **2007**, *46*, 2310; (b) Li, J.; Liu, X.; Lee, D. *Org. Lett.* **2012**, *14*, 410-413.

2.1.3 Preparation of ring-rearrangement metathesis substrates 3g and 3i



The substrates **3g** and **3i** were also prepared from allylation and protection of the corresponding cyclopentyl carboaldehydes. Different from the previous synthetic routes, the cyclopentyl carboaldehydes were synthesized based on strategy of diallylation and ring-closing metathesis.

To a stirred solution of 2-arylacetic acid (5 g) in dry MeOH was added sulfuric acid (0.5 mL) dropwise and heated to reflux. Stirring was then continued for 2 hours. The reaction mixture was then cooled and poured into saturated aqueous $NaHCO_3$ and extracted with EtOAc. The combined organic fractions were dried over Na_2SO_4, filtered, and concentrated under reduced pressure to yield the corresponding methyl 2-arylacetate, which was used for next step without further purification.

A solution of methyl 2-arylacetate (1.0 equiv.), allyl bromide (1.5 equiv.) and tetrabutylammonium iodide (0.05 equiv.) in tetrahydrofuran (0.5 M) at 0° C was treated portionwise with sodium hydride (60 % in oil, 1.0 equiv.). The solution was allowed to warm to 25° C and heated at reflux for 1 hour. The mixture was cooled to 0° C, treated with saturated ammonium chloride solution. The mixture was partitioned between ethyl acetate and water. The organic phase was washed with saturated sodium bicarbonate solution and brine, dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was used for next step without further purification.

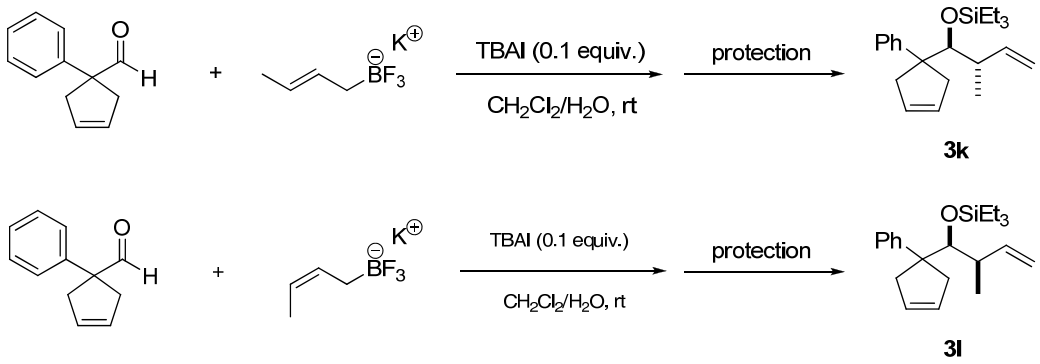
To a stirring solution of diisopropylamine (1.2 equiv.) in THF (1 M) at -78 °C was added nBuLi (2.5 M in hexanes, 1.1 equiv.). This solution was allowed to stir at -78°C for 1 h. Methyl 2-aryl, 2-allylacetate (1.0 equiv.) in THF was added dropwise over 30 min. After the solution

stirred at -78°C for an additional 15 min, allyl bromide (1.5 equiv.) was added dropwise over 10 min. The reaction was allowed to warm up to rt, stirred for 4 h, and quenched by addition of 3 M HCl. The aqueous layer was extracted with Et_2O. The combined organics were washed with brine, dried over $MgSO_4$, and concentrated. The crude residue was purified by silica gel chromatography to provide the intermediate ester as colorless oil.

To a stirring solution of 2, 2-diallyl ester in CH_2Cl_2 was added Grubbs 1st generation catalyst (3 mol%). The RCM reaction was monitored by TLC until the completion of the reaction. Then the reaction solution was concentrated by rotavap and purified by silica gel column chromatography to give colorless oil.

To a stirring solution of cyclopentyl carboxylate (1.0 equiv.) in mixed solvents (hexanes : Et_2O = 3:1) was added DIBAL (1.0 M in hexanes, 1.0 equiv.) solution at -78 °C. After 30 min, the reaction was quenched with MeOH and saturated aqueous Potassium Sodium tartrate solution. After stirring for 30 min, the aqueous layer was extracted with Et_2O. The extracted organic layers were dried over $MgSO_4$, filtered and concentrated by rotary evaporation. The product was isolated by flash chromatography as colorless oil. Sometimes overreduction cannot be avoided. In those cases, a Swern-type oxidation was adopted to reoxidize the corresponding primary alcohol to the aldehyde.

2.1.4 Preparation of ring-rearrangement metathesis substrates 3k and 3l



Potassium crotyltrifluoroborates were prepared according to the reported procedures. [2] Crotylation was carried out according to Batey's procedure[3]: To a solution of the aldehyde (1.0

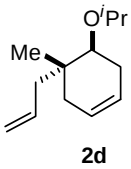
[2] (a) Preparation of boric acid: Roush, W. R.; Ando, K.; Powers, D. B.; Palkowitz, A. D.; Halterman, R. L. *J. Am. Chem. Soc.*, **1990**, *112*, 6339-6348; Preparation of Potassium organotrifluoroborate: Vedejs, E.; Chapman, R. W.; Fields, S. C.; Lin, S.; Schrimpf, M. R. *J. Org. Chem.* **1995**, *60*, 3020.

mmol) and tetrabutylammonium iodide (36.9 mg, 0.1 mmol) in CH_2Cl_2 (3 mL) was added the corresponding crotyltrifluoroborate (174 mg, 1.10 mmol) and water (3 mL). The biphasic reaction mixture was vigorously stirred for 15 min at rt. The reaction mixture was then diluted with CH_2Cl_2 (5 mL). The layers were separated and the aqueous layer was extracted with CH_2Cl_2 (3 x 5 mL). The combined organic extracts were dried ($MgSO_4$), filtered and concentrated *in vacuo* to afford a clear, colorless oil. This material was passed through a short plug of silica gel using EtOAc as the eluent. The resulting eluate was concentrated *in vacuo* to afford the desired homoallylic alcohols. Substrates **3k** and **3l** were prepared according to the previously described protection of the homoallylic alcohols.

2.2 General procedure of ring-rearrangement metathesis

To a solution of the Grubbs 2nd generation catalyst (5 mol%) under ethylene atmosphere was added slowly a solution of **3** (1.0 equiv.) in CH_2Cl_2 (0.1 M). Then the reaction was warmed up to 40 ^{o}C. The reaction was monitored by TLC or ^{1}H NMR until completion of the reaction. Then the reaction solution was concentrated by rotavap and purified by silica gel column chromatography to give the ring-rearrangement metathesis products **4**.

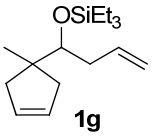
2.3 Characterization data for ring-rearrangement metathesis



2d

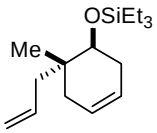
Known compound **1d** was prepared according to the literature.[1b] **2d**, colorless oil, 65% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.86 (tdd, *J* = 15.2, 10.8, 7.5 Hz, 1H), 5.55 (m, 2H), 5.03 (d, *J* = 10.0 Hz, 1H), 5.03 (d, *J* = 16.5 Hz, 1H), 3.62 (septet, *J* = 6.2 Hz, 1H), 3.22 (dd, *J* = 7.5, 5.3 Hz, 1H), 2.35-2.25 (m, 1H), 2.18 (dd, *J* = 13.5, 7.8 Hz, 1H), 2.00 (dd, *J* = 13.2, 7.3 Hz, 2H), 1.94-1.79 (m, 2H), 1.12 (t, *J* = 6.2 Hz, 6H), 0.88 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 135.35, 125.73, 123.92, 117.06, 77.72, 70.34, 43.77, 36.21, 29.65, 23.62, 22.27, 18.82; LRMS (CI) calcd for $C_{13}H_{22}O$ [M] 194.1, found 194.1.

[3] Crotylation, Thadani, A. N.; Batey, R. A. *Org. Lett.* **2002**, *4*, 3827-3830.



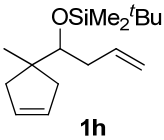
1g

1g, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.87 (tdd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.60 (m, 2H), 5.04 (d, *J* = 17.2 Hz, 1H), 5.00 (d, *J* = 10.6 Hz, 1H), 3.58 (dd, *J* = 7.5, 3.6 Hz, 1H), 2.44-2.28 (m, 2H), 2.28-2.10 (m, 2H), 1.92 (m, 2H), 0.99 (s, 3H), 0.95 (t, *J* = 7.9 Hz, 9H), 0.60 (q, *J* = 7.9 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 137.24, 129.30, 128.85, 116.05, 79.69, 47.50, 44.48, 43.83, 39.21, 23.24, 7.12, 5.66; HRMS (EI) calcd for $C_{16}H_{29}OSi$ [M-1] 265.1988, found 265.1991.



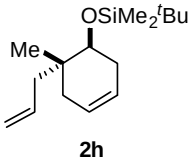
2g

2g, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.84 (tdd, *J* = 17.4, 10.3, 7.5 Hz, 1H), 5.60-5.45 (m, 2H), 5.03 (d, *J* = 10.3 Hz, 1H), 5.02 (d, *J* = 16.8 Hz, 1H), 3.60 (dd, *J* = 8.0, 5.4 Hz, 1H), 2.26-2.13 (m, 2H), 2.07-1.93 (m, 2H), 1.92-1.78 (m, 2H), 0.97 (t, *J* = 7.9 Hz, 9H), 0.85 (s, 3H), 0.60 (q, *J* = 8.1 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 136.36, 125.72, 123.80, 117.04, 73.18, 43.94, 37.14, 35.94, 32.57, 17.75, 7.02, 5.34; HRMS (CI) calcd for $C_{16}H_{29}OSi$ [M-1] 265.1988, found 265.1982.



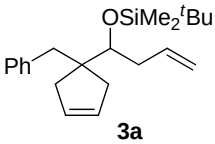
1h

1f, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.88 (tdd, *J* = 17.2, 10.1, 7.2 Hz, 1H), 5.58 (m, 2H), 5.03 (dd, *J* = 17.2, 1.6 Hz, 1H), 4.99 (dd, *J* = 10.2, 0.8 Hz, 1H), 3.58 (dd, *J* = 6.3, 4.2 Hz, 1H), 2.44-2.25 (m, 3H), 2.25-2.15 (m, 1H), 1.92 (m, 2H), 1.01 (s, 3H), 0.89 (s, 9H), 0.06 (s, 3H), 0.05 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 137.22, 129.37, 128.74, 115.93, 79.38, 47.66, 44.76, 44.00, 39.38, 26.08, 23.36, 18.33, -3.13, -4.24; HRMS (EI) calcd for $C_{16}H_{29}OSi$ [M-1] 265.1988, found 265.1993.



2h

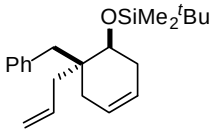
2h, colorless oil, 89% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.82 (ddt, *J* = 15.2, 10.2, 7.8 Hz,1H), 5.52 (m, 2H), 5.03 (d, *J* = 10.1 Hz, 1H), 5.02 (d, *J* = 16.8 Hz, 1H), 3.57 (dd, *J* = 7.9, 5.5 Hz, 1H), 2.27-2.09 (m, 2H), 1.99 (m, 2H), 1.84 (m, 2H), 0.89 (s, 9H), 0.85 (s, 3H), 0.05 (s, 3H), 0.05 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 135.29, 125.68, 123.77, 117.12, 73.06, 43.93, 37.12, 35.84, 32.52, 25.91, 18.12, 17.89, -3.78, -4.81; HRMS (EI) calcd for $C_{16}H_{29}OSi$ [M-1] 265.1988, found 265.1993.



3a

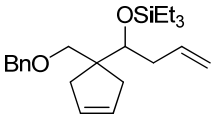
3a, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.28-7.22 (m, 2H), 7.22-7.18 (m, 3H), 5.94 (dtt, *J* = 14.0 7.2, 4.0 Hz, 1H), 5.39 (s, 2H), 5.09 (d, *J* = 17.3 Hz, 1H), 5.06 (d, *J* = 11.3 Hz, 1H), 3.74 (dd, *J* = 6.3, 3.9 Hz, 1H), 2.81 (m,

2H), 2.52-2.43 (m, 1H), 2.42-2.25 (m, 5H), 0.96 (s, 9H), 0.12 (s, 3H), 0.09 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 139.68, 137.32, 130.52, 129.42, 129.10, 127.68, 125.74, 116.12, 79.28, 51.69, 41.90, 41.57, 40.42, 39.16, 26.20, 18.45, -2.92, -4.21; HRMS (EI) calcd for $C_{22}H_{34}OSi$ [M] 342.2379, found 342.2356.



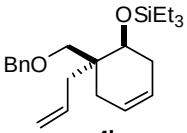
4a

4a, colorless oil, 96% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.33 (t, *J* = 7.3 Hz, 2H), 7.26 (t, *J* = 7.3 Hz, 1H), 7.22 (d, *J* = 7.1 Hz, 2H), 5.97-5.82 (m, 1H), 5.68 (m, 2H), 5.11 (d, *J* = 10.2 Hz, 1H), 5.04 (d, *J* = 16.9 Hz, 1H), 3.93 (dd, *J* = 6.9, 5.6 Hz, 1H), 2.82 (m, 2H), 2.45-2.29 (m, 2H), 2.21 (m, 1H), 2.01 (m, 1H), 1.87 (m, 1H), 1.80 (m, 1H), 1.03 (s, 9H), 0.19 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 139.16, 134.83, 131.15, 127.78, 125.92, 125.83, 124.02, 117.87, 71.25, 40.78, 38.74, 37.51, 32.43, 31.37, 26.08, 18.31, -3.31, -4.70; HRMS (CI) calcd for $C_{17}H_{21}O$ $[M+1]^+$ 343.2457 found 343.2458.



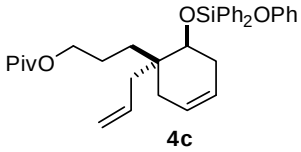
3b

3b, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38-7.32 (m, 4H), 7.31-7.27 (m, 1H), 5.90 (tdd, *J* = 14.6, 10.2, 7.2 Hz, 1H), 5.58 (m, 2H), 5.02 (d, *J* = 15.3 Hz, 1H), 5.00 (d, *J* = 8.7 Hz, 1H), 4.50 (m, 2H), 3.93 (dd, *J* = 6.9, 3.5 Hz, 1H), 3.37 (m, 2H), 2.49-2.28 (m, 3H), 2.26-2.04 (m, 3H), 0.96 (t, *J* = 7.9 Hz, 9H), 0.61 (q, *J* = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.83, 137.38, 129.42, 129.17, 128.27, 127.58, 127.39, 115.98, 75.45, 75.06, 73.22, 51.15, 38.93, 38.61, 38.49, 7.12, 5.64; HRMS (CI) calcd for $C_{23}H_{35}O_2Si$ [M-1] 371.2406, found 371.2401.



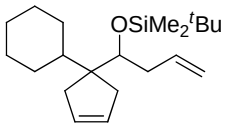
4b

4b, colorless oil, 95% yield, *dr* ≥ 10 : 1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38 (m, 4H), 7.31 (m, 1H), 5.95-5.84 (m, 1H), 5.69-5.62 (m, 1H), 5.59-5.52 (m, 1H), 5.07 (d, *J* = 16.0 Hz, 1H), 5.07 (d, *J* = 11.1 Hz, 1H), 4.51 (m, 2H), 3.93 (t, *J* = 4.0 Hz, 1H), 3.54 (d, *J* = 8.6 Hz, 1H), 3.30 (d, *J* = 8.6 Hz, 1H), 2.29 (m, 1H), 2.22 (m, 2H), 2.09-1.98 (m, 2H), 1.86-1.75 (m, 1H), 0.99 (t, *J* = 8.0 Hz, 9H), 0.64 (q, *J* = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 139.07, 135.26, 128.25, 127.56, 127.34, 125.41, 123.12, 117.34, 73.33, 72.30, 69.27, 41.19, 36.84, 31.51, 28.30, 7.08, 5.32; HRMS (CI) calcd for $C_{23}H_{35}O_2Si$ [M-1] 371.2406, found 371.2413.



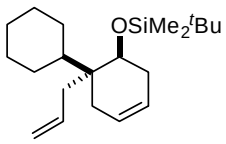
4c

Known compound **3c** was prepared according to the literature.[1b] **4c,** colorless oil, 94% yield, *dr* = 15 : 1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.71 (t, *J* = 7.1 Hz, 4H), 7.49-7.33 (m, 6H), 7.15 (t, *J* = 7.7 Hz, 2H), 6.92 (d, *J* = 7.8 Hz, 3H), 5.70 (td, *J* = 16.7, 7.6 Hz, 1H), 5.56 (m, 1H), 5.40 (m, 1H), 4.98 (m, 2H), 3.95 (t, *J* = 5.1 Hz, 1H), 3.91 (m, 2H), 2.27-2.11 (m, 2H), 2.07 (m, 2H), 1.92 (m, 2H), 1.64-1.47 (m, 3H), 1.37 (m, 1H), 1.17 (s, 9H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 178.55, 154.47, 135.05, 134.99, 134.18, 132.64, 132.49, 130.57, 130.50, 129.34, 127.94, 125.52, 123.32, 121.61, 119.65, 117.70, 73.38, 65.14, 39.09, 38.74, 38.18, 32.94, 31.49, 29.11, 27.26, 22.60; HRMS (CI) calcd for $C_{35}H_{43}O_4Si$ $[M+1]^+$ 555.2931, found 555.2924.



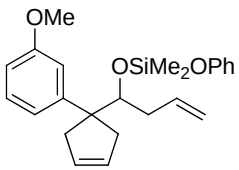
3d

3d, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.91 (tdd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.53 (s, 2H), 5.02 (dd, *J* = 19.2, 1.5 Hz, 1H), 4.99 (d, *J* = 10.8 Hz, 1H), 3.80 (t, *J* = 4.6 Hz, 1H), 2.45-2.31 (m, 2H), 2.29-2.12 (m, 3H), 1.99 (d, *J* = 17.1 Hz, 1H), 1.78-1.61 (m, 4H), 1.60-1.51 (m, 1H), 1.40 (t, *J* = 11.7 Hz, 1H), 1.25-1.07 (m, 3H), 1.03-0.93 (m, 2H), 0.87 (s, 9H), 0.07 (s, 3H), 0.04 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 137.49, 129.97, 129.78, 115.71, 76.34, 52.30, 44.12, 38.73, 38.51, 37.78, 27.41, 26.92, 26.82, 26.78, 26.04, 25.74, 18.35, -3.00, -4.46; HRMS (CI) calcd for $C_{21}H_{37}OSi$ [M-1] 333.2614, found 333.2608.



4d

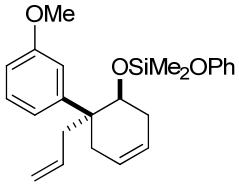
4d, colorless oil, 82% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.96-5.85 (m, 1H), 5.62-5.55 (m, 1H), 5.48 (m, 1H), 4.98 (d, *J* = 16.8 Hz, 1H), 4.95 (dd, *J* = 9.0, 0.9 Hz, 1H), 3.90 (t, *J* = 4.3 Hz, 1H), 2.25 (m, 1H), 2.17-1.99 (m, 3H), 1.94 (m, 2H), 1.79 (m, 3H), 1.64 (m, 3H), 1.23-1.05 (m, 5H), 0.87 (s, 9H), 0.05 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 136.93, 126.33, 122.94, 116.11, 70.33, 42.09, 41.61, 36.33, 32.02, 31.92, 27.93, 27.84, 27.80, 27.43, 27.11, 25.90, 18.16, -3.78, -4.80; HRMS (CI) calcd for $C_{21}H_{37}OSi$ [M-1] 333.2614, found 333.2622.



3e

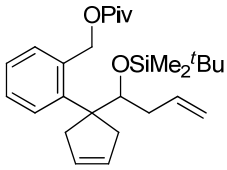
3e, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.22 (m, overlapped, *J* = 7.6 Hz, 3H), 6.96 (t, *J* = 7.4 Hz, 1H), 6.91-6.85 (m, overlapped, 4H), 6.75 (dd, *J* = 8.1, 2.3 Hz, 1H), 5.80 (tdd, *J* = 11.5, 9.2, 7.1 Hz, 1H), 5.70 (2s, 2H), 4.94 (d, *J* = 15.5 Hz, 1H), 4.93 (d, *J* = 12.0 Hz, 1H), 3.97 (dd, *J* = 9.1, 2.1

Hz, 1H), 3.79 (s, 3H), 2.93 (m, 1H), 2.85-2.64 (m, overlapped, 3H), 2.23 (dd, *J* = 14.8, 6.6 Hz, 1H), 1.98-1.88 (m, 1H), 0.12 (s, 3H), 0.06 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 159.14, 149.02, 136.85, 129.59, 129.37, 129.10, 128.60, 121.39, 120.76, 119.89, 116.76, 114.86, 110.66, 80.14, 55.84, 55.18, 41.79, 41.04, 38.49, -1.77, -2.14; LRMS (CI) calcd for $C_{24}H_{30}O_3Si$ [M] 394.20, found 394.20.



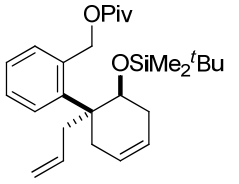
4e

4e, colorless oil, 84% yield, *dr* = 8 : 1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.25-7.13 (m, 3H), 7.02 (m, 2H), 6.94 (t, *J* = 7.4 Hz, 1H), 6.84 (m, 2H), 6.76 (dd, *J* = 8.1, 1.8 Hz, 1H), 5.77 (d, *J* = 9.8 Hz, 1H), 5.54-5.46 (m, 1H), 5.39 (dddd, *J* = 16.9, 10.0, 8.6, 5.8 Hz, 1H), 4.96 (d, *J* = 17.0 Hz, 1H), 4.90 (d, *J* = 9.4 Hz, 1H), 4.22 (dd, *J* = 7.6, 4.6 Hz, 1H), 3.78 (s, 3H), 2.80 (m, 1H), 2.65 (m, 1H), 2.31-2.13 (m, 3H), 1.81 (m, 1H), 0.20 (s, 3H), 0.15 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 161.56, 154.57, 144.65, 134.79, 129.39, 128.25, 125.85, 124.43, 121.54, 120.82, 119.88, 117.23, 114.69, 110.92, 75.07, 55.08, 45.12, 43.46, 33.16, 32.47, -1.89, -2.31; HRMS (CI) calcd for $C_{24}H_{30}O_3Si$ [M] 394.1964, found 394.1972.



3f

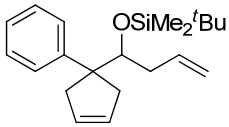
3f, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.37-7.33 (m, 1H), 7.32 (d, *J* = 7.4 Hz, 1H), 7.25-7.18 (m, 2H), 5.71 (m, 3H), 5.27 (m, 2H), 4.89 (d, *J* = 15.6 Hz, 1H), 4.89 (d, *J* = 11.5 Hz, 1H), 3.89 (t, *J* = 5.1 Hz, 1H), 2.97 (m, 2H), 2.78 (m, 2H), 2.39-2.25 (m, 1H), 2.03 (m, 1H), 1.24 (s, 9H), 0.84 (s, 9H), -0.04 (s, 3H), -0.40 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 178.34, 146.73, 136.81, 135.03, 131.09, 130.42, 129.59, 128.91, 127.46, 126.25, 115.96, 77.84, 65.34, 57.06, 42.49, 39.28, 27.27, 26.17, 18.21, -3.72, -5.03; HRMS (CI) calcd for $C_{27}H_{43}O_3Si$ $[M+1]^+$ 443.2982, found 443.2955.



4f

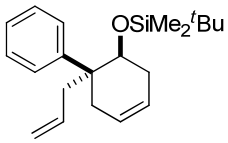
4f, colorless oil, 92% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.40-7.35 (m, 1H), 7.32 (m, 1H), 7.23 (m, 2H), 5.77 (s, 1H), 5.59 (m, 1H), 5.40 (m, 2H), 5.27 (m, 1H), 4.91 (d, *J* = 17.0 Hz, 1H), 4.82 (d, *J* = 10.0 Hz, 1H), 4.30 (s, 1H), 2.88 (d, *J* = 16.3 Hz, 1H), 2.65 (d, *J* = 11.1 Hz, 1H), 2.48-2.29 (m, 1H), 2.23-2.13 (m, 1H), 2.00 (d, *J* = 17.7 Hz, 1H), 1.23 (s, 9H), 0.67 (s, 9H), -0.07 (s, 3H), -0.46 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 178.49, 142.85, 135.16, 134.48, 131.13, 129.32, 127.60, 126.32,

126.17, 123.11, 116.79, 72.65, 65.22, 46.79, 38.88, 32.54, 27.26, 25.64, 17.86, -4.62, -5.46; HRMS (CI) calcd for $C_{27}H_{41}O_3Si$ [M-1] 441.2825, found 441.2817.



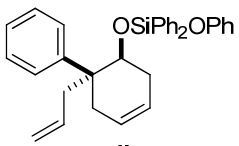
3g

3g, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.34 (d, *J* = 7.7 Hz, 2H), 7.29 (t, *J* = 7.6 Hz, 2H), 7.19 (t, *J* = 7.2 Hz, 1H), 5.74-5.64 (m, 3H), 4.96-4.80 (m, 2H), 3.90-3.84 (m, 1H), 2.96 (d, *J* = 16.6 Hz, 1H), 2.81-2.68 (m, 2H), 2.63 (d, *J* = 16.5 Hz, 1H), 2.27-2.18 (m, 1H), 1.96-1.88 (m, 1H), 0.91 (s, 9H), 0.02 (s, 3H), -0.11 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 147.43, 137.14, 129.35, 129.26, 128.18, 127.66, 125.73, 115.85, 78.06, 56.43, 41.86, 41.34, 39.50, 26.27, 26.17, 18.33, -3.20, -4.75; HRMS (CI) calcd for $C_{21}H_{33}OSi$ $[M+1]^+$ 329.2301, found 329.2305.



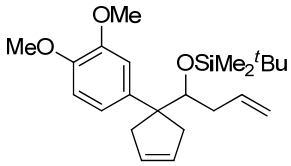
4g

4g, colorless oil, 95% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.44 (d, *J* = 7.4 Hz, 2H), 7.27 (t, *J* = 7.6 Hz, 2H), 7.19 (t, *J* = 7.3 Hz, 1H), 5.85-5.70 (m, 1H), 5.56-5.46 (m, 1H), 5.36 (dddd, *J* = 16.8, 10.0, 8.6, 5.9 Hz, 1H), 4.95 (d, *J* = 17.0 Hz, 1H), 4.89 (d, *J* = 10.2 Hz, 1H), 3.99 (dd, *J* = 8.0, 4.6 Hz, 1H), 2.87 (dd, *J* = 13.6, 5.7 Hz, 1H), 2.71-2.60 (m, 1H), 2.25-2.10 (m, 3H), 1.72-1.59 (m, 1H), 0.87 (s, 9H), 0.03 (s, 3H), -0.04 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 142.95, 135.11, 128.44, 127.30, 125.92, 125.84, 124.64, 116.93, 74.74, 45.35, 43.97, 33.51, 32.88, 25.88, 18.08, -4.08, -4.98; HRMS (CI) calcd for $C_{21}H_{33}OSi$ $[M+1]^+$ 329.2301, found 329.2308.



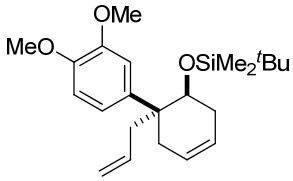
4h

Known compound **3h** was prepared according to the literature.[1b] **4h,** colorless oil, 94% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.62-7.55 (m, 2H), 7.52 (d, *J* = 7.4 Hz, 1H), 7.48-7.33 (m, 7H), 7.33-7.26 (m, 4H), 7.22 (d, *J* = 8.0 Hz, 1H), 7.11 (t, *J* = 7.8 Hz, 2H), 6.96-6.75 (m, 3H), 5.80-5.68 (m, 1H), 5.40 (m, 1H), 5.37-5.25 (m, 1H), 4.88 (m, 1H), 4.85 (d, *J* = 10.53 Hz, 1H), 4.30 (dd, *J* = 6.3, 4.5 Hz, 1H), 2.72 (m, 2H), 2.21 (m, 3H), 1.90 (m, 1H), 1.37-1.22 (m, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 154.45, 143.26, 135.08, 134.96, 134.64, 130.47, 130.36, 129.27, 127.97, 127.87, 127.80, 127.64, 126.00, 125.75, 123.98, 121. 52, 119.69, 117.23, 75.41, 45.01, 42.92, 32.35, 32.17; HRMS (CI) calcd for $C_{33}H_{33}O_2Si$ $[M+1]^+$ 489.2250, found 489.2259.



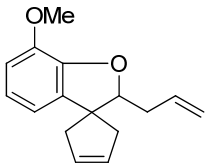
3i

3i, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.93 (d, *J* = 2.0 Hz, 1H), 6.83 (dd, *J* = 8.4, 2.0 Hz, 1H), 6.78 (d, *J* = 8.4 Hz, 1H), 5.72-5.64 (m, 3H), 4.88 (d, *J* = 8.3 Hz, 1H), 4.87 (d, *J* = 17.0 Hz, 1H), 3.88 (s, 1H), 3.86 (s, 1H), 3.81 (dd, *J* = 5.6, 4.8 Hz, 1H), 2.96 (d, *J* = 16.3 Hz, 1H), 2.68 (m, 2H), 2.55 (d, *J* = 16.5 Hz, 1H), 2.27-2.11 (m, 1H), 1.98-1.79 (m, 1H), 0.91 (s, 9H), 0.03 (s, 3H), -0.05 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 148.20, 147.21, 139.83, 137.12, 129.39, 129.24, 120.09, 115.83, 112.28, 110.33, 78.04, 56.14, 55.96, 55.85, 42.05, 41.99, 39.64, 26.16, 18.30, -3.24, -4.61; HRMS (EI) calcd for $C_{23}H_{36}O_3Si$ [M] 388.2434, found 388.2428.



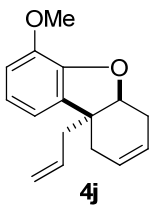
4i

4i, colorless oil, 93% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.14 (d, *J* = 1.8 Hz, 1H), 6.87 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.75 (d, *J* = 8.5 Hz, 1H), 5.81-5.69 (b, 1H), 5.48 (b, 1H), 5.42-5.32 (m, 1H), 4.94 (d, *J* = 17.0 Hz, 1H), 4.89 (d, *J* = 10.2 Hz, 1H), 3.94 (dd, *J* = 8.7, 4.6 Hz, 1H), 3.85 (s, overlapped, 6H), 2.88 (dd, *J* = 13.6, 5.5 Hz, 1H), 2.60 (dd, *J* = 17.9, 3.4 Hz, 1H), 2.13 (m, 3H), 1.66 (m, 1H), 0.89 (s, 9H), 0.04 (s, 3H), 0.02 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 147.88, 147.17, 135.16, 125.84, 125.06, 120.76, 116.87, 112.45, 109.85, 75.36, 55.93, 55.68, 45.16, 44.56, 32.98, 25.97, 18.11, -4.05, -4.90; HRMS (EI) calcd for $C_{23}H_{36}O_3Si$ [M] 388.2434, found 388.2443.



3j

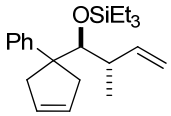
3j, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.85-6.78 (m, 2H), 6.77-6.72 (m, 1H), 5.98 (tdd, *J* = 17.0, 10.3, 6.8 Hz, 1H), 5.82-5.67 (m, 2H), 5.19 (d, *J* = 17.0 Hz, 1H), 5.11 (d, *J* = 10.2 Hz, 1H), 4.50 (dd, *J* = 8.5, 4.8 Hz, 1H), 3.88 (s, 3H), 2.88 (m, 2H), 2.66 (td, *J* = 14.5, 7.2 Hz, 1H), 2.59-2.45 (m, 2H), 2.25 (d, *J* = 16.8 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 146.21, 144.36, 138.98, 134.59, 129.23, 128.91, 121.54, 117.39, 114.32, 111.14, 92.32, 55.97, 54.27, 46.29, 40.77, 35.39; LRMS (EI) calcd for $C_{16}H_{18}O_2$ [M] 242.13, found 242.13.



4j

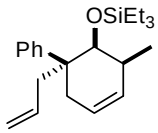
4j, colorless oil, 90% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 6.81 (t, *J* = 7.8 Hz, 1H), 6.71 (d, *J* = 7.3 Hz, 1H), 6.69 (d, *J* = 7.3 Hz, 1H), 5.84 (s, 2H), 5.75-5.62 (m, 1H), 5.09 (d, *J* = 16.0 Hz, 1H), 5.08 (d, *J* = 11.5 Hz, 1H), 4.83 (t, *J* = 4.3 Hz, 1H), 3.85 (s, 3H), 2.62 (dt, *J* = 15.5, 3.9 Hz, 1H), 2.46 (m, 2H), 2.33 (dd, *J* = 15.5, 4.4 Hz,

1H), 2.28 (m, overlapped, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 148.12, 144.04, 135.70, 133.93, 128.21, 125.82, 120.84, 118.49, 115.24, 110.80, 87.27, 55.75, 49.41, 45.31, 34.37, 28.88; HRMS (EI) calcd for $C_{16}H_{18}O_2$ [M] 242.1307, found 242.1316.



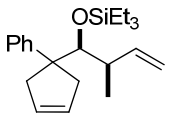
3k

3k, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.28 (m, 4H), 7.21-7.14 (m, 1H), 5.73-5.62 (m, 2H), 5.56-5.49 (m, 1H), 4.72 (dd, *J* = 10.3, 1.8 Hz, 1H), 4.62 (dd, *J* = 17.4, 2.0 Hz, 1H), 3.93 (s, 1H), 2.92-2.76 (m, 2H), 2.62 (m, 2H), 2.15 (p, *J* = 7.2 Hz, 1H), 0.98 (t, *J* = 7.9 Hz, 9H), 0.94, (d, *J* = 7.0 Hz, 3H), 0.62 (q, *J* = 7.8 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 147.76, 140.74, 129.75, 128.28, 127.81, 127.62, 125.69, 113.13, 82.49, 57.05, 44.26, 40.43, 38.83, 21.49, 7.21, 5.79; HRMS (EI) calcd for $C_{22}H_{34}OSi$ [M] 342.2379, found 342.2388.



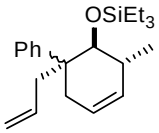
4k

4k, colorless oil, 80% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.35-7.24 (m, 4H), 7.18 (t, *J* = 6.9 Hz, 1H), 5.73 (tdd, *J* = 9.8, 5.0, 2.5 Hz, 1H), 5.41 (d, *J* = 9.6 Hz, 1H), 5.15 (ddd, *J* = 16.4, 9.7, 5.7 Hz, 1H), 4.86 (d, *J* = 17.0 Hz, 1H), 4.80 (d, *J* = 10.0 Hz, 1H), 4.10 (d, *J* = 3.9 Hz, 1H), 2.64 (m, 1H), 2.46 (b, 1H), 2.28 (m, 1H), 2.19-2.08 (m, 1H), 0.80 (t, *J* = 7.9 Hz, 9H), 0.29 (q, *J* = 7.69 Hz, 3H), 0.15 (m, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 145.45, 135.03, 129.86, 127.76, 127.55, 125.86, 124.38, 116.88, 78.00, 45.56, 42.28, 34.54, 29.24, 16.14, 7.17, 5.08; HRMS (EI) calcd for $C_{22}H_{34}OSi$ [M] 342.2379, found 342.2375.



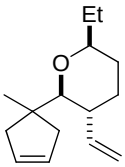
3l

3l, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.35 (d, *J* = 7.4 Hz, 2H), 7.29 (t, *J* = 7.7 Hz, 2H), 7.20 (t, *J* = 7.2 Hz, 1H), 5.87-5.71 (m, 2H), 5.69-5.63 (m, 1H), 4.89 (d, *J* = 10.3 Hz, 1H), 4.85 (d, *J* = 17.2 Hz, 1H), 3.95 (d, *J* = 1.43 Hz, 1H), 3.12-2.98 (m, 1H), 2.80-2.67 (m, 2H), 2.66-2.58 (m, 1H), 2.29-2.17 (m, 1H), 1.00 (t, *J* = 8.0 Hz, 9H), 0.63 (q, *J* = 8.0 Hz, 6H), 0.50 (d, *J* = 6.80 Hz, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 147.06, 145.04, 129.68, 128.67, 127.98, 127.69, 125.75, 112.60, 80.57, 56.94, 42.92, 40.64, 39.85, 13.45, 7.21, 5.67; HRMS (EI) calcd for $C_{22}H_{34}OSi$ [M] 342.2379, found 342.2388.



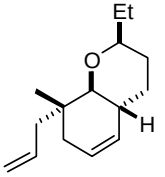
4l-major

4l, colorless oil, 95% yield, *dr* = 2.5 : 1; Major isomer: ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.47 (d, *J* = 7.3 Hz, 2H), 7.24 (t, *J* = 7.4 Hz, 2H), 7.18 (t, *J* = 7.2 Hz, 1H), 5.70 (tdd, *J* = 9.8, 4.9, 2.4 Hz, 1H), 5.39-5.25 (m, 2H), 4.94 (d, *J* = 17.0 Hz, 1H), 4.88 (d, *J* = 10.1 Hz, 1H), 3.59 (d, *J* = 8.9 Hz, 1H), 3.04 (dd, *J* = 13.4, 5.6 Hz, 1H), 2.64 (m, 1H), 2.13-2.04 (m, 2H), 1.66-1.55 (m, 1H), 1.03 (t, *J* = 7.9 Hz, 9H), 0.98 (d, *J* = 7.2 Hz, 3H), 0.73 (q, *J* = 7.9 Hz, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 142.44, 135.10, 132.48, 128.84, 127.15, 125.85, 124.32, 116.83, 82.74, 45.91, 45.84, 36.86, 35.79, 18.84, 7.27, 5.70; HRMS (EI) calcd for $C_{22}H_{34}OSi$ [M] 342.2348, found 342.2386.



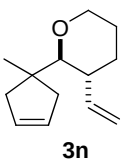
3m

3m, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.66 (td, *J* = 17.1, 9.8 Hz, 1H), 5.58 (b, 2H), 5.01 (dd, *J* = 17.1, 1.6 Hz, 1H), 4.89 (dd, *J* = 10.2, 1.9 Hz, 1H), 3.16-3.05 (m, 1H), 2.97 (d, *J* = 9.5 Hz, 1H), 2.46 (m, 1H), 2.25-2.15 (m, 2H), 1.97 (m, 2H), 1.73-1.55 (m, 2H), 1.51-1.35 (m, 3H), 1.29-1.16 (m, 1H), 1.00 (s, 3H), 0.92 (t, *J* = 7.4 Hz, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 141.47, 128.97, 128.87, 113.61, 88.37, 79.19, 46.96, 46.21, 45.98, 44.59, 32.36, 31.26, 29.41, 22.53, 10.30; HRMS (EI) calcd for $C_{15}H_{24}O$ [M] 220.1827, found 220.1832.



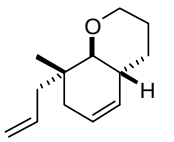
4m (*dr* 5:1)

4m, colorless oil, 94% yield, *dr* = 5 : 1; Major isomer: ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.91-5.76 (m, 1H), 5.49 (ddd, *J* = 9.5, 4.6, 2.2 Hz, 1H), 5.33-5.27 (m, 1H), 5.07-4.99 (m, 2H), 3.21-3.09 (m, 1H), 2.83 (d, *J* = 9.2 Hz, 1H), 2.27-1.90 (m, 4H), 1.91-1.83 (m, 1H), 1.66 (m, 2H), 1.54-1.47 (m, 1H), 1.46-1.38 (m, 1H), 1.32-1.18 (m, 2H), 0.98-0.92 (m, 3H), 0.90 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 135.51, 128.66, 125.40, 117.13, 83.60, 79.74, 43.91, 37.57, 36.36, 32.27, 30.30, 29.40, 19.01, 10.41; HRMS (EI) calcd for $C_{15}H_{25}O$ [M] 220.1827, found 220.1833.



3n

3n, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.66 (td, *J* = 17.1, 9.8 Hz, 1H), 5.58 (b, 2H), 5.02 (dd, *J* = 17.1, 1.3 Hz, 1H), 4.90 (dd, *J* = 10.2, 1.9 Hz, 1H), 3.99 (tdd, *J* = 11.5, 4.2, 1.6 Hz, 1H), 3.35 (dt, *J* = 12.0, 2.5 Hz, 1H), 2.97 (d, *J* = 9.6 Hz, 1H), 2.32 (m, 2H), 1.96 (m, 2H) 1.85 (m, 2H), 1.63 (m, 2H), 1.64 (dtd, *J* = 8.7, 8.5, 4.2 Hz, 1H), 1.01 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 141.32, 128.84, 113.70, 88.99, 68.64, 46.75, 46.18, 44.89, 32.17, 25.96, 22.45; HRMS (EI) calcd for $C_{13}H_{20}O$ $[M]^{+}$ 192.1514, found 192.1521.

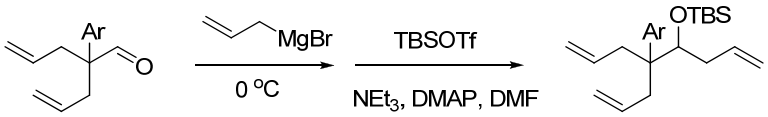


4n (*dr* 4.7:1)

4n, colorless oil, 93% yield, *dr* = 4.7 : 1; Major isomer: ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.90-5.77 (m, 1H), 5.49 (ddd, *J* = 9.7, 4.9, 2.5 Hz, 1H), 5.28 (dd, *J* = 9.9, 1.1 Hz, 1H), 5.07-5.01 (m, 2H), 4.06-3.99 (m, 1H), 3.40 (m, 1H), 2.83 (d, *J* = 9.2 Hz, 1H), 2.19-1.99 (m, 3H), 1.89 (dd, *J* = 12.7, 1.5 Hz, 1H), 1.77-1.51 (m, 3H), 1.29-1.21 (m, 2H), 0.91 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 135.14, 128.68, 125.33, 117.38, 84.65, 69.08, 44.00, 37.63, 36.70, 30.21, 26.99, 24.43, 18.73; HRMS (EI) calcd for $C_{13}H_{20}O$ [M] 192.1514, found 192.1512.

3. Diastereoselective ring-closing metathesis of acyclic trienes

3.1 Preparation of acyclic trienes 5g, 5i, 5o and 5p

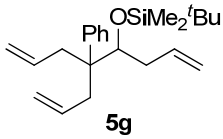


Acyclic trienes **5g, 5i, 5o** and **5p** were prepared from allylation and protection of 2-allyl-2-arylpent-4-enals, which were synthesized according to the previously described procedures in **2.1.3**.

3.2 General procedure of ring-rearrangement metathesis

To a solution of the Grubbs 2nd generation catalyst (5 mol%) under ethylene atmosphere was added slowly a solution of **5** (1.0 equiv.) in CH_2Cl_2 (0.1 M). Then the reaction was warmed up to 40 ^{o}C. The reaction was monitored by TLC or ^{1}H NMR until completion of the reaction. Then the reaction solution was concentrated by rotavap and purified by silica gel column chromatography to give the ring-rearrangement metathesis products **4**.

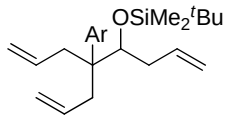
3.3 Characterization data for ring-rearrangement metathesis



5g

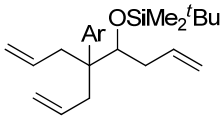
5g, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.43 (d, *J* = 8.1 Hz, 2H), 7.30 (t, *J* = 7.6 Hz, 2H), 7.21 (t, *J* = 7.2 Hz, 1H), 5.78-5.54 (m, 3H), 5.05 (m, 3H), 4.96 (d, *J* = 9.4 Hz, 1H), 4.87 (d, *J* = 9.1 Hz, 1H), 4.84 (d, *J* = 16.7 Hz, 1H), 3.93 (dd, *J* = 6.2, 4.0 Hz, 1H), 2.79 (dd, *J* = 14.3, 6.5 Hz, 1H), 2.70 (dd, *J* = 14.2, 8.3 Hz,

1H), 2.56 (dd, *J* = 14.3, 6.9 Hz, 2H), 2.17 (ddd, *J* = 8.9, 5.2, 2.6 Hz, 1H), 1.89 (td, *J* = 14.0, 6.9 Hz, 1H), 0.95 (s, 9H), 0.10 (s, 3H), 0.07 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 143.87, 137.01, 136.10, 134.83, 127.99, 127.68, 125.94, 117.85, 116.58, 115.96, 78.73, 48.70, 38.90, 38.83, 26.24, 18.42, -3.31, -4.02; HRMS (ESI) calcd for $C_{23}H_{36}OSi$ [M] 356.2536, found 356.2528.



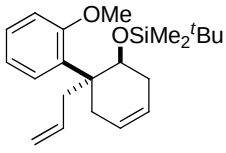
5i, Ar = 3,4-dimethoxyphenyl

5i, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.08 (d, *J* = 1.8 Hz, 1H), 6.87 (dd, *J* = 8.5, 2.0 Hz, 1H), 6.78 (d, *J* = 8.5 Hz, 1H), 5.83-5.70 (m, 1H), 5.61 (m, 2H), 5.12-4.91 (m, 4H), 4.86 (d, *J* = 8.8 Hz, 1H), 4.83 (d, *J* = 16.4 Hz, 1H), 3.90 (dd, *J* = 6.2, 4.1 Hz, 1H), 3.87 (s, 6H), 2.77 (m, *J* = 14.2, 6.1 Hz, 1H), 2.56 (dq, *J* = 14.2, 7.2 Hz, 2H), 2.45 (dd, *J* = 14.3, 8.0 Hz, 1H), 2.20-2.09 (m, 1H), 1.94-1.81 (m, 1H), 0.94 (s, 9H), 0.10 (s, 6H), 0.06 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 148.19, 147.24, 136.99, 136.57, 135.99, 134.78, 119.97, 117.99, 116.64, 115.95, 111.95, 110.11, 78.27, 55.98, 55.71, 48.25, 39.54, 38.95, 38.75, 26.24, 18.39, -3.31, -4.07; HRMS (EI) calcd for $C_{25}H_{40}O_3Si$ [M] 416.2747, found 416.2744.



5o, Ar = 2-methoxyphenyl

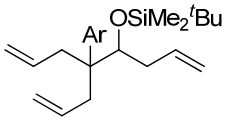
5o, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.25 (d, *J* = 7.7 Hz, 1H), 7.23 (t, *J* = 7.0 Hz, 1H), 6.91 (t, *J* = 7.6 Hz, 1H), 6.85 (d, *J* = 8.1 Hz, 1H), 6.15 (m, Hz, 1H), 5.61 (m, 1H), 5.46 (m, 1H), 5.07 (d, *J* = 17.1 Hz, 1H), 5.00 (d, *J* = 10.1 Hz, 1H), 4.93 (d, *J* = 17.0 Hz, 1H), 4.82 (m, 3H), 4.62 (t, *J* = 5.3 Hz, 1H), 3.83 (s, 3H), 3.02 (dd, *J* = 14.1, 6.3 Hz, 1H), 2.77 (m, 1H), 2.66 (m, 1H), 2.19-2.13 (m, 2H), 0.94 (s, 9H), 0.06 (s, 3H), 0.03 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 158.00, 137.77, 136.95, 132.23, 129.54, 127.63, 120.50, 115.84, 115.71, 115.46, 111.38, 54.90, 49.99, 39.39, 38.48, 37.93, 26.26, 18.41, -3.28, -4.16; HRMS (EI) calcd for $C_{24}H_{38}O_2Si$ [M] 386.2641, found 386.2645.



4o

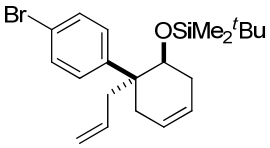
4o, colorless oil, 88% yield; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.20-7.15 (m, 1H), 7.12 (d, *J* = 7.8 Hz, 1H), 6.87 (t, *J* = 7.5 Hz, 1H), 6.83 (t, *J* = 7.9 Hz, 1H), 5.81-5.73 (m, 1H), 5.63-5.53 (m, 1H), 5.29-5.16 (m, 1H), 4.84 (d, *J* = 17.0 Hz, 1H), 4.74 (m, 2H), 3.83 (s, 3H), 3.00-2.90 (m, 1H), 2.76 (d, *J* = 16.2 Hz, 1H), 2.38 (m, 1H), 2.25 (dd, *J* = 13.2, 8.5 Hz, 1H), 2.12-1.98 (m, 2H), 0.63 (s, 9H), -0.12 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 158.04, 136.36, 132.91, 129.38, 127.08, 125.83, 122.81,

120.18, 115.62, 110.65, 69.15, 54.67, 45.36, 35.75, 32.26, 28.46, 25.63, 17.81, -4.64, -5.85; HRMS (CI) calcd for $C_{22}H_{35}O_2Si$ $[M+1]^+$ 359.2406, found 359.2411.



5p, Ar = 4-bromophenyl

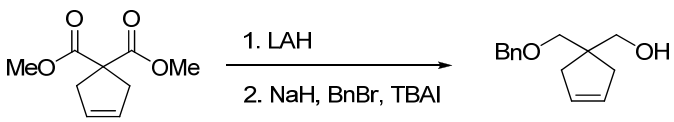
5p, colorless oil; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.43 (d, *J* = 8.5 Hz, 2H), 7.32 (d, *J* = 8.6 Hz, 2H), 5.74 (dtd, *J* = 14.6, 8.5, 6.5 Hz, 1H), 5.68-5.54 (m, 2H), 5.09 (m, 2H), 5.02 (d, *J* = 17.0 Hz, 1H), 4.97 (d, *J* = 10.2 Hz, 1H), 4.88 (d, *J* = 9.3 Hz, 1H), 4.86 (d, *J* = 16.9 Hz, 1H), 3.89 (dd, *J* = 6.2, 4.1 Hz, 1H), 2.77 (m, 1H), 2.64 (dd, *J* = 14.18, 8.26 Hz, 1H), 2.58-2.44 (m, 2H), 2.20-2.10 (m, 1H), 1.91-1.82 (m, 1H), 0.95 (s, 9H), 0.11 (s, 3H), 0.07 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 142.85, 136.60, 135.36, 134.21, 130.70, 129.96, 120.11, 118.35, 117.14, 116.22, 77.95, 48.54, 39.18, 38.84, 38.38, 26.23, 18.41, -3.33, -4.02; HRMS (EI) calcd for $C_{23}H_{34}OBrSi$ [M-1] 433.1562, found 433.1554.



4p

4p, colorless oil, 91% yield, *dr* = 13 : 1; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38 (d, *J* = 8.6 Hz, 2H), 7.33 (d, *J* = 8.7 Hz, 2H), 5.78-5.70 (m, 1H), 5.48 (dd, *J* = 9.4, 1.8 Hz, 1H), 5.35 (ddd, *J* = 16.4, 8.7, 6.1 Hz, 1H), 4.95 (d, *J* = 17.1 Hz, 1H), 4.90 (d, *J* = 10.4 Hz, 1H), 3.94 (dd, *J* = 8.6, 4.7 Hz, 1H), 2.86 (dd, *J* = 13.7, 5.8 Hz, 1H), 2.58 (dd, *J* = 18.1, 3.2 Hz, 1H), 2.19-2.09 (m, 3H), 1.58 (ddd, *J* = 14.1, 7.1, 3.9 Hz, 1H), 0.89 (s, 9H), 0.04 (s, 3H), 0.02 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 141.71, 134.54, 130.49, 130.33, 125.62, 125.02, 119.95, 117.37, 74.68, 45.31, 44.23, 34.11, 32.88, 25.89, 18.09, -4.04, -4.90; HRMS (CI) calcd for $C_{21}H_{32}OBrSi$ $[M+1]^+$ 407.1406, found 407.1410.

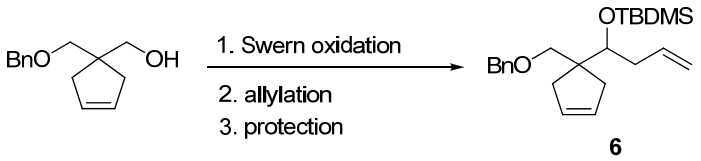
4. Total synthesis of (±)-nitramine



To a suspension of $LiAlH_4$ (2.2 g, 57.9 mmol, 3.0 equiv) in 50 mL of THF stirred at 0 °C under N_2 atmosphere, a solution of dimethyl cyclopent-3-ene-1,1-dicarboxylate (3.55 g, 19.3 mmol) in 20 mL of diethyl ether was added dropwise. The mixture was stirred for 1 h at room temperature.

Then, at 0 °C, water (2 mL), an aqueous solution 3 N in NaOH (4 mL) and water (6 mL) were successively added dropwise and stirring was continued for 15 min more. The resulting mixture was then filtered over Celite and rinsed several times with diethyl ether. The organic layer was separated, dried on anhydrous $MgSO_4$, filtered, and concentrated under reduced pressure to afford cyclopent-3-ene-1,1-diyldimethanol as a white solid, which was used directly for next step without further purification.

According to the known procedure reported by Kubota[4], to a solution of the above diol in THF (60 mL) was added NaH (60% dispersion in mineral oil, 656 mg, 1.0 equiv.) slowly at 0 °C. After stirring at room temperature for 1 h, benzyl bromide (1.95 mL, 1.0 equiv.) and a catalytic amount of tetrabutylammonium iodide (TBAI) were added and stirred at room temperature for 12 h. The reaction mixture was extracted with ethyl acetate and saturated NH_4Cl. The organic solvent was washed with brine, dried over $MgSO_4$, and concentrated. Purification on a silica gel column with hexane-ethyl acetate gave (1-(benzyloxymethyl)cyclopent-3-enyl)methanol (2.82 g, yield 67% over two steps) and recovered diol (315 mg, 13% over two steps). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.39-7.28 (m, 5H), 5.60 (s, 2H), 4.53 (s, 2H), 3.61 (s, 2H), 3.52 (s, 2H), 2.23 (m, 4H).



6

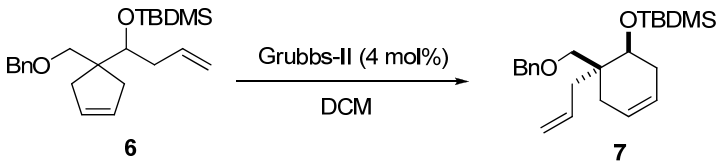
A dry DMSO (1.45 mL, 2.2 equiv.) was slowly added over a stirred oxalyl chloride (1.32g, 1.1 equiv.) in dry dichloromethane (0.5 M) at -78 °C. After the evolution of gas ceased, a solution of (1-(benzyloxymethyl)cyclopent-3-enyl)methanol (2.02 g, 9.25 mmol) in dry dichloromethane was slowly added to the resulting solution of activated DMSO at -78 °C. After 60 min, triethylamine (5 equiv.) was added. After 30 min, the reaction was slowly warmed up to room temperature. The reaction was quenched by the addition of 10% NH_4Cl solution. The mixture was washed by dichloromethane for three times and the collected organic phases were dried over anhydrous $MgSO_4$ followed by concentration to give crude product, which was used directly without further purification. ^{1}H NMR ($CDCl_3$, 500 MHz) δ 9.66 (s, 1H), 7.63-6.98 (m, 5H), 5.80-

[4] Ikeda, Y.; Kubota, D.; Nagasaki, Y. *Bioconjugate Chem.*, **2010**, *21*, 1685–1690.

5.41 (m, 2H), 4.53 (s, 2H), 3.63 (s, 2H), 2.79-2.66 (m, 2H), 2.35 (td, J = 12.6, 2.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 203.23, 138.02, 128.44, 128.38, 127.73, 127.60, 73.44, 73.20, 57.41, 36.93.

An allyl magnesium bromide solution (1.0M, 12 mL) in diethyl ether was added slowly to the above aldehyde solution in THF at 0 ^{o}C. After addition, the reaction solution was slowly warmed up to room temperature. Once TLC indicated the reaction was completed, a saturated NH_4Cl solution was added to quench the reaction. Then the reaction solution was extracted with diethyl ether for three times and washed by brine. The collected organic phase was dried over anhydrous $MgSO_4$ followed by concentration to afford crude alcohol, which was further purified by column chromatograph to give allyllic alcohol (2.15 g, yield 90% in two steps).

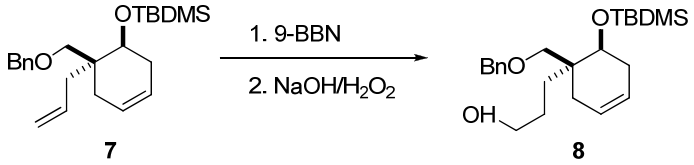
To a solution of the allylic alcohol (2.03 g, 7.86 mmol), triethylamine (2.1 mL, 15 mmol) and catalytic amount 4-dimethylaminopyridine in anhydrous DMF was added slowly *tert*-butyldimethylsilyl triflate (1.8 mL, 7.86 mmol) at 0 °C. Then the reaction was heated up to 80 °C until completion. Then the reaction was quenched by the addition of 1N HCl, extracted with diethyl ether, dried over anhydrous $MgSO_4$ and concentrated under vacuum to afford crude oil, which was purified by column chromatograph to give the metathesis substrate **6** (2.75 g, yield 94%); ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.37 (m, 4H), 7.34-7.28 (m, 1H), 5.93 (tdd, J = 17.1, 10.1, 7.2 Hz, 1H), 5.65-5.54 (m, 2H), 5.01 (d, J = 17.2 Hz, 1H), 4.99 (d, J = 9.5 Hz, 1H), 4.51 (m, 2H), 3.97-3.93 (m, 1H), 3.38 (m, 2H), 2.51-2.36 (m, 3H), 2.29-2.18 (m, 2H), 2.13-2.03 (m, 1H), 0.91 (s, 9H), 0.10 (s, 3H), 0.09 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.82, 137.32, 129.35, 129.26, 128.31, 127.63, 127.44, 115.82, 75.12, 75.02, 73.22, 51.29, 38.96, 38.88, 38.83, 26.10, 18.33, -3.16, -4.48; HRMS (CI) calcd for $C_{23}H_{35}O_2Si$ [M-1] 371.2406, found 371.2405.



6 **7**

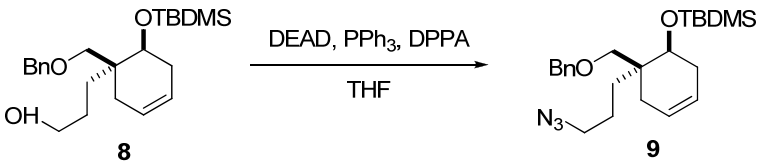
To a solution of the Grubbs 2nd generation catalyst (100 mg, 0.04 equiv.) under ethylene atmosphere was slowly added a solution of **6** (1.11 g, 2.98 mmol) in CH_2Cl_2 (80 mL). The reaction was monitored by TLC or ^{1}HNMR until completion of the reaction. Then the reaction

solution was concentrated by rotavap and purified by silica gel column chromatography to give the ring-rearrangement metathesis product **7** (1.05 g, yield 95%). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.35 (m, 4H), 7.29 (dd, *J* = 8.4, 4.1 Hz, 1H), 5.91-5.78 (tdd, *J* = 16.3, 11.2, 7.5 Hz, 1H), 5.64-5.47 (m, 2H), 5.03 (d, *J* = 15.6 Hz, 1H), 5.03 (d, *J* = 11.5 Hz, 1H), 4.47 (m, 2H), 3.86 (t, *J* = 4.0 Hz, 1H), 3.37 (m, 2H), 2.30-2.10 (m, 3H), 1.98 (m, 2H), 1.76 (m, 1H), 0.87 (s, 9H), 0.05 (s, 3H), 0.04 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 139.02, 135.19, 128.24, 127.53, 127.32, 125.28, 123.00, 117.35, 73.25, 72.28, 69.08, 41.15, 36.69, 31.34, 28.16, 25.88, 18.09, -4.04, -4.96; HRMS (CI) calcd for $C_{23}H_{37}O_2Si$ $[M+1]^+$ 373.2563, found 373.2534.

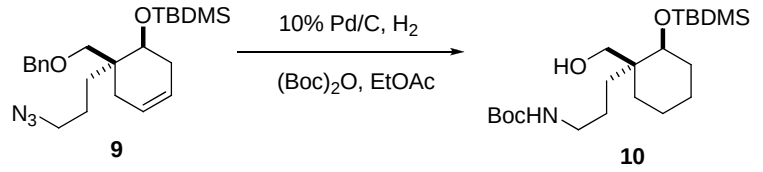


7 **8**

To a solution of diene **7** (1.54 g, 4.12 mmol) in THF (10 mL) was added a THF solution of 9-BBN (0.5 M, 14 mL, 7.0 mmol) slowly at 0 °C and the reaction mixture was stirred for 7 h at that temperature. After the addition of 3M NaOH (7.35 mL, 22.1 mmol) solution and H_2O_2 solution (30%, 7.35 mL, 77.2 mmol), the reaction mixture was stirred for 30 minutes. Organic materials were extracted with ethyl acetate two times and the combined organic extracts were washed with brine two times and dried over anhydrous Na_2SO_4, and concentrated in vacuo after filtration. Purification by silica gel column chromatography gave the primary alcohol **8** (1.03 g) in 64% yield. ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.34-7.31 (m, 4H), 7.28 (td, *J* = 7.9, 2.2 Hz, 1H), 5.61-5.44 (m, 2H), 4.45 (m, 2H), 3.86 (t, *J* = 4.0 Hz, 1H), 3.57 (t, *J* = 6.6 Hz, 2H), 3.48 (d, *J* = 8.7 Hz, 1H), 3.25 (d, *J* = 8.7 Hz, 1H), 2.27-2.18 (m, 1H), 2.04-1.91 (m, 2H), 1.82 (m, 1H), 1.75-1.62 (m, 2H), 1.57-1.46 (m, 2H), 1.46-1.35 (m, 1H), 0.86 (s, 9H), 0.04 (s, 3H), 0.03 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.86, 128.26, 127.58, 127.40, 125.24, 123.04, 73.26, 72.24, 69.37, 63.88, 40.41, 31.37, 28.57, 28.07, 25.86, 22.71, 18.08, -4.07, -4.97; HRMS (CI) calcd for $C_{23}H_{38}O_3Si$ $[M+1]^+$ 391.2669, found 391.2660.

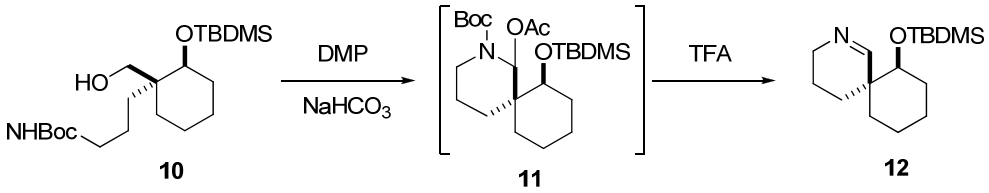


To a solution of alcohol **8** (321 mg, 0.82 mmol) in THF (3 mL) was added triphenylphosphine (865 mg, 3.30 mmol), diphenyl phosphorazidate (355 μL, 1.65 mmol) and diethyl azodicarboxylate (575 mg, 3.30 mmol) at 0° C. Then the reaction was stirred for 30 minutes at room temperature. The mixture was concentrated and purified the residue by column chromatography to afford the azide **9** (317 mg, yield 93%). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38-7.30 (m, 4H), 7.30-7.27 (m, 1H), 5.63-5.44 (m, 2H), 4.45 (m, 2H), 3.85 (t, *J* = 4.2 Hz, 1H), 3.46 (d, *J* = 8.8 Hz, 1H), 3.24 (d, *J* = 8.8 Hz, 1H), 3.22-3.17 (dt, *J* = 7.0, 2.3 Hz, 2H), 2.21 (dd, *J* = 17.9, 1.9 Hz, 1H), 2.07-1.90 (m, 2H), 1.70 (d, *J* = 17.4 Hz, 1H), 1.62-1.53 (m, 3H), 1.51-1.34 (m, 2H), 0.86 (s, 9H), 0.04 (s, 3H), 0.04 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 138.81, 128.28, 127.57, 127.43, 125.13, 123.14, 73.28, 71.99, 69.46, 52.42, 40.50, 31.41, 29.68, 28.61, 25.84, 23.19, 18.07, -4.05, -4.98; HRMS (EI) calcd for $C_{23}H_{37}O_2N_3Si$ [M] 415.2655, found 415.2648.



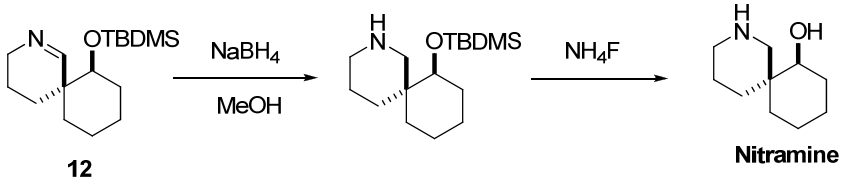
A solution of the azide **9** (440 mg, 1.05 mmol) in ethyl acetate was added to a solution of 10% palladium/charcoal (300 mg) and di-tert-butyl dicarbonate (231 mg, 1.1 equiv.) in ethyl acetate (11 mL). The palladium catalyst was washed by ethyl acetate for several times before use in order to avoid side reaction (mainly deprotonation of silyl group). Then the reaction mixture was flushed by hydrogen gas for three times and stirred under atmospheric pressure of hydrogen gas at room temperature for 24 hrs. Once TLC indicated the completion of reaction, the reaction was filtered through a pad of celite, concentrated and purified by silica gel column chromatography to give the primary alcohol **10** (401 mg, yield 95 %). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.61 (s, 1H), 4.16 (d, *J* = 10.4 Hz, 1H), 3.55 (dd, *J* = 9.9, 4.2 Hz, 1H), 3.28 (d, *J* = 10.5 Hz, 2H), 3.11 (td, *J* = 12.7, 6.2 Hz, 2H), 1.98-1.85 (m, 1H), 1.71 (m, 3H), 1.54-1.40 (m, 13H), 1.28-1.17 (m, 2H), 1.19-

1.01 (m, 2H), 0.88 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 155.99, 79.42, 78.94, 85.00, 41.40, 40.87, 32.70, 32.22, 31.08, 28.46, 25.83, 24.40, 23.16, 20.99, 17.92, -4.12, -5.03; HRMS (CI) calcd for $C_{21}H_{42}O_4SiN$ [M-1] 400.2883, found 400.2877.



10 **11** **12**

To a solution of the primary alcohol **10** (129 mg, 0.32 mmol) in dichloromethane (3 mL) was added Dess-Martin Periodinane (204 g, 1.5 equiv.) followed by sodium bicarbonate (3 equiv.) at room temperature. After stirred for 2 h, the reaction mixture was flushed over a plug of cotton, the filtrate was then poured into a mixture of $Na_2S_2O_3$ and $NaHCO_3$ solution and extracted with diethyl ether. The solution was dried over anhydrous $MgSO_4$, and concentrated in vacuum to provide a residue, whose ^{1}H NMR showed a formation of cyclic product incorporating acetoxy group. Treatment of the cyclized intermediate in dichloromethane with trifluoroacetic acid at room temperature for 30 min followed by basic workup yielded a crude aldimine **12**. ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.95 (s, 1H), 3.62 (d, *J* = 17.0 Hz, 1H), 3.52 (m, 1H), 3.48-3.37 (m, 1H), 1.93 (ddd, *J* = 13.1, 8.8, 3.9 Hz, 1H), 1.76-1.56 (m, 5H), 1.55-1.41 (m, 4H), 1.38 (m, 1H), 1.21-1.11 (m, 1H), 0.89 (s, 9H), 0.03 (s, 6H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 169.86, 74.53, 49.51, 41.02, 31.69, 29.66, 28.99, 25.87, 25.80, 21.48, 20.62, 19.13, 18.09, -4.09, -5.04; HRMS (EI) calcd for $C_{16}H_{32}NOSi$ $[M+1]^+$ 282.2253, found 282.2243.



12 **Nitramine**

The aldimine **12** solution in MeOH was carefully treated with $NaBH_4$ (12 mg, 0.32 mmol). The reaction mixture was stirred for 10 min and quenched with 1 M NaOH. The product was extracted with ether. The ether extract was washed with saturated aqueous NaCl and dried over $MgSO_4$. The solvent was evaporated to give the crude protected nitramine as a colorless oil. To a solution of the protected nitramine in methanol was added ammonium fluoride (37 mg, 1 mmol)

at 50 ^{o}C. After stirring overnight, TLC showed the completion of the reaction. The mixture was flushed through a pad of silica gel. The filtrate was concentrated under reduced pressure and purified using silica gel column chromatography to deliver the nature product (±)-nitramine (44 mg, 82% yield over four steps from **10**). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.28 (b, 1H), 3.59 (dd, *J* = 9.8, 3.8 Hz, 1H), 3.49 (d, *J* = 11.9 Hz, 1H), 3.04 (d, *J* = 11.1 Hz, 1H), 2.63 (dt, *J* = 11.3, 3.2 Hz, 1H), 2.40 (d, *J* = 11.9 Hz, 1H), 2.19-2.03 (m, 1H), 1.90-1.80 (m, 1H), 1.76 (m, 1H), 1.67 (m, 1H), 1.63-1.48 (m, 2H), 1.38 (m, 2H), 1.27 (m, 4H), 1.05 (m, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 76.78, 52.15, 46.67, 37.91, 36.88, 35.97, 32.29, 24.02, 23.31, 21.08; HRMS (CI) calcd for $C_{10}H_{20}ON$ [M] 170.1545, found 170.1551.

5. ^{1}H NMR and ^{13}C NMR spectra