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Intramolecular Cycloaddition Reactions of Silyl Nitronate Tethered to Vinylsilyl Group: 2-Nitroalkanols as Precursors for Amino Polyols

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Instrumentation

IR spectra were recorded on a Horiba Fourier transform infrared spectrophotometer Model FT-210 instrument. ¹H-NMR and ¹³C-NMR spectra were recorded on a Varian Mercury-300 (300 MHz for proton and 75 MHz for carbon-13). The chemical shifts are given in δ units relative to internal CHCl₃ (7.26 ppm for ¹H) or CDCl₃ (77 ppm for ¹³C). All NMR experiments were performed using deuteriochloroform as a solvent unless otherwise indicated. Mass spectra were obtained on a JEOL JMS-DX303 instrument relying on a JMA-DA5000 mass data system. Elemental analyses were made with a Perkin-Elmer 2400 CHN Elemental Analyzer.

Analytical Procedure and Data Presentation

Analytical thin layer chromatography was performed on Merck pre-coated silica gel 60 F-254 (0.25 mm thickness). ¹H-NMR spectral data were indicated in the form: δ -value of signal (peak multiplicity, integrated number of protons and coupling constant (if any)). Splitting patterns are abbreviated as follows: s, singlet; d, doublet; t, triplet; m, multiplet; b, broad.

General Reaction Procedure

All reactions, unless otherwise noted, were conducted under a nitrogen or an argon atmosphere. Liquid reagents were transferred via a dry hypodermic syringe from sure seal bottles to a reaction flask through a rubber septa wired on to the reaction flask. The septa can also serve to permit evacuation to eliminate air and introduce the inert gas by means of a steady stream of inert gas flowing system. Organic extracts were concentrated by evaporation with a rotary evaporator evacuated at around 60 mmHg. Column chromatography, unless otherwise specified, was performed on a Merck silica gel 60 7734 using an appropriate ratio of ethyl acetate-hexane mixed solvent and abbreviated as CC.

Materials

Unless otherwise noted, materials were obtained from commercial suppliers and reagent grade materials were used without further purification. Dimethyl sulfoxide (DMSO), triethylamine (Et₃N), dichloromethane (CH₂Cl₂), acetonitrile (CH₃CN) were freshly distilled from CaH₂ prior to use. Methanol was distilled from magnesium turnings under argon. Tetrahydrofuran were purchased from Kanto Chemical Co., Inc is dehydrated and stabilizer-free grade and was used as received.

General procedure for intramolecular cycloaddition reactions of 2-nitroalkanols (1).

To a solution of 2-nitroalkanol (**1**, 1.0 equiv) in CH₃CN (10 mL/mmol of **1**) were added Et₃N (3.0 equiv), chlorodimethylvinylsilane (2.2 equiv), and DMAP (0.1 equiv) at 0 °C. The resulting solution was stirred at 0 °C for 30 min and then warmed up to rt. The reaction mixture was stirred at rt until the disappearance of **1** by an NMR diagnosis for a small aliquot of the reaction mixture. The reaction was quenched by the addition of H₂O and extracted two times with hexane/AcOEt (3 : 1). The combined organic layers were dried over MgSO₄, filtered, and concentrated by a rotary evaporator, then an oil rotary pump under high vacuum to give a cycloadduct. No further purification of the product by means of silica gel column chromatography (Merck silica gel 60 7734) was made because of the lability of the cycloadduct on the chromatography using hexane-EtOAc as an eluent.

(1R*,5S*,8R*)-2-Dimethylvinylsiloxo-8-isopropyl-2-aza-3,7-dioxo-6-(dimethyl)silabicyclo-[3.3.0]octane (2a). IR (film) 2960, 1597, 1470, 1408, 1254 cm⁻¹; ¹H-NMR δ 0.25 & 0.26 & 0.27 (s, 12H, SiMe × 4), 0.91 & 0.97 (d, 6H, *J* = 6.9 Hz, Me₂C), 1.74—1.85 (m, 1H, Me₂CH), 2.22 (ddd, 1H, *J* = 5.8, 8.5, 11.0 Hz, SiCH), 3.36 (dd, 1H, *J* = 4.4, 8.2Hz, SiOCH), 3.93 (dd, 1H, *J* = 8.2, 8.5 Hz, NCH), 3.98 (dd, 1H, *J* = 5.8, 7.4 Hz, NOCHH), 4.39 (dd, 1H, *J* = 7.4, 11.0 Hz, NOCHH), 5.80 (dd, 1H, *J* = 4.1, 20.3 Hz, SiCH=C), 6.02 (dd, 1H, *J* = 4.1, 14.8 Hz, SiC=CHH), 6.20 (dd, 1H, *J* = 14.8, 20.3 Hz, SiC=CHH); ¹³C-NMR δ -2.3, -2.2, 0.3, 16.7, 19.2, 28.7, 32.9, 69.8, 82.0, 83.4, 133.2, 137.1; exact mass, *m/z* 301.15244 (calcd for C₁₅H₂₇NO₃Si₂ *m/z* 301.15295); Anal. Calcd for C₁₅H₂₇NO₃Si₂: C, 51.78; H, 9.03. Found: C, 51.66; H, 8.97.

(1R*,5S*,8R*)-2-Dimethylvinylsiloxo-8-pentyl-2-aza-3,7-dioxo-6-(dimethyl)silabicyclo-[3.3.0]octane (2b). IR (film) 2956, 1254 cm⁻¹; ¹H-NMR δ 0.26 × 2 & 0.27 & 0.28 (s, 12H, SiMe), 0.8—1.8 (m, 11H, C₅H₁₁), 2.22 (ddd, 1H, *J* = 5.8, 8.8, 11.0 Hz, SiCH), 3.44 (m, 1H, C₅H₁₁CH), 3.77 (dd, 1H, *J* = 8.5, 8.8 Hz, NCH), 3.98 (dd, 1H, *J* = 5.8, 7.4 Hz, NOCHH), 4.39 (dd, 1H, *J* = 7.4, 11.0 Hz, NOCHH), 5.81 (dd, 1H, *J* = 4.4, 20.1 Hz, SiCH=C), 6.04 (dd, 1H, *J* = 4.4, 14.8 Hz, SiC=CHH), 6.20 (dd, 1H, *J* = 14.8, 20.1 Hz, SiC=CHH); ¹³C-NMR δ -2.4, -2.3 × 2, 0.3, 14.1, 22.6, 25.3, 28.4, 31.9, 36.9, 69.8, 78.7, 84.6, 133.3, 137.0.

(1R*,5S*,8R*)-2-Dimethylvinylsiloxo-8-cyclohexyl-2-aza-3,7-dioxo-6-(dimethyl)sila-

bicyclo[3.3.0]octane (2c). IR (film) 2926, 1606, 1257 cm^{-1} ; ^1H -NMR δ 0.23 & 0.24 & 0.26 (s, 12H, SiMe), 1.0—1.8 (m, 11H, cyclohexyl), 2.20 (ddd, 1H, J = 6.0, 8.5, 11.0 Hz, SiCH), 3.33 (dd, 1H, J = 4.9, 8.3 Hz, SiOCH), 3.94—4.00 (m, 2H, NCH, NOCHH), 4.38 (dd, 1H, J = 7.4, 11.0 Hz, NOCHH), 5.80 (dd, 1H, J = 4.1, 20.1 Hz, SiCH=C), 6.02 (dd, 1H, J = 4.1, 14.8 Hz, SiC=CHH), 6.19 (dd, 1H, J = 14.8, 20.1 Hz, SiC=CHH); ^{13}C -NMR δ -2.4, -2.3, 0.2, 26.0, 26.2, 26.4, 27.2, 28.4, 29.5, 42.9, 69.7, 81.7, 82.7, 133.1, 137.0; exact mass, m/z 341.18398 (calcd for $\text{C}_{16}\text{H}_{31}\text{NO}_3\text{Si}_2$ m/z 341.18425); Anal. Calcd for $\text{C}_{16}\text{H}_{31}\text{NO}_3\text{Si}_2$: C, 56.26; H, 9.15. Found: C, 56.41; H, 9.08.

(1*R,5*S**,8*R**)-2-Dimethylvinylsiloxy-8-phenyl-2-aza-3,7-dioxa-6-(dimethyl)silabicyclo[3.3.0]octane (2d).** IR (film) 2960, 1948, 1913, 1811, 1254 cm^{-1} ; ^1H -NMR δ 0.13 (s, 3H, SiMe), 0.14 (s, 3H, SiMe), 0.37 (s, 3H, SiMe), 0.42 (s, 3H, SiMe), 2.36 (ddd, 1H, J = 5.8, 8.5, 11.0 Hz, SiCH), 3.97 (dd, 1H, J = 8.5, 8.7 Hz, NCH), 4.11 (dd, 1H, J = 5.8, 7.4 Hz, NOCHH), 4.47 (dd, 1H, J = 7.4, 11.0 Hz, NOCHH), 4.50 (d, 1H, J = 8.8 Hz, PhCH), 5.70 (dd, 1H, J = 4.4, 19.8 Hz, SiCH=C), 5.92 (dd, 1H, J = 4.4, 14.8 Hz, SiC=CHH), 6.05 (dd, 1H, J = 14.8, 19.8 Hz, SiC=CHH), 7.2—7.5 (m, 5H, Ar-H); ^{13}C -NMR δ -2.5, -2.4, 0.1, 28.8, 69.9, 79.7, 87.1, 125.4, 127.3, 128.1, 133.1, 136.7, 142.8.

(1*R,5*S**,8*R**)-2-Dimethylvinylsiloxy-1-methyl-8-phenyl-2-aza-3,7-dioxa-6-(dimethyl)silabicyclo[3.3.0]octane (2e).** IR (film) 2960, 1556, 1454, 1255 cm^{-1} ; ^1H -NMR δ 0.19 (s, 3H, SiMe), 0.22 (s, 3H, SiMe), 0.36 (s, 3H, SiMe), 0.41 (s, 3H, SiMe), 0.85 (s, 3H, Me), 1.90 (dd, 1H, J = 6.1, 11.3 Hz, SiCH), 4.11 (dd, 1H, J = 6.1, 7.7 Hz, NOCHH), 4.56 (dd, 1H, J = 7.7, 11.3 Hz, NOCHH), 4.79 (s, 1H, PhCH), 5.78 (dd, 1H, J = 4.1, 20.1 Hz, SiCH=C), 5.98 (dd, 1H, J = 4.1, 14.8 Hz, SiC=CHH), 6.15 (dd, 1H, J = 14.8, 20.1 Hz, SiC=CHH), 7.2—7.5 (m, 5H, Ar-H); ^{13}C -NMR δ -2.2, -2.1, -0.1, 17.9, 35.7, 70.7, 81.4, 87.1, 126.1, 127.0, 127.5, 133.0, 137.2, 140.2; exact mass, m/z 349.15253 (calcd for $\text{C}_{17}\text{H}_{27}\text{NO}_3\text{Si}_2$ m/z 349.15295); Anal. Calcd for $\text{C}_{17}\text{H}_{27}\text{NO}_3\text{Si}_2$: C, 58.41; H, 7.79. Found: C, 58.31; H, 7.66.

(1*R,5*S**,8*R**)-2-Dimethylvinylsiloxy-8-(4-methoxyphenyl)-2-aza-3,7-dioxa-6-(dimethyl)silabicyclo[3.3.0]octane (2f).** IR (film) 2958, 2058, 1900, 1257 cm^{-1} ; ^1H -NMR δ 0.12 & 0.13 & 0.35 & 0.40 (s, 12H, SiMe₃), 2.35 (ddd, 1H, J = 6.0, 8.8, 11.0 Hz, SiCH), 3.80 (s, 3H, OMe), 3.95 (dd, 1H, J = 8.5, 8.8 Hz, ONCH), 4.09 (dd, 1H, J = 6.0, 7.4 Hz, NOCHH), 4.4—4.5 (m, 2H, NOCHH, SiOCH), 5.70 (dd, 1H, J = 4.1, 19.8 Hz, SiCH=C), 5.91 (dd, 1H, J = 4.1, 14.8 Hz, SiC=CHH), 6.05 (dd, 1H, J = 14.8, 19.8 Hz, SiC=CHH); ^{13}C -NMR δ -2.5, -2.4, 0.1, 28.8, 55.2, 70.0, 79.4, 87.1, 113.5, 126.8, 133.2, 135.0, 136.7, 158.9.

(1*R,5*S**,8*R**)-2-Dimethylvinylsiloxy-6-(4-methoxyphenyl)-1-methyl-2-aza-3,7-dioxa-6-(dimethyl)silabicyclo[3.3.0]octane (2g).** IR (film) 2960, 2062, 1907, 1250 cm^{-1} ; ^1H -NMR δ 0.19 (s, 3H, SiMe), 0.21 (s, 3H, SiMe), 0.35 (s, 3H, SiMe), 0.39 (s, 3H, SiMe), 0.85 (s, 3H, Me), 1.88 (dd, 1H, J = 6.3, 11.3 Hz, SiCH), 3.80 (s, 3H, MeO), 4.10 (dd, 1H, J = 6.3, 7.4 Hz, NOCHH), 4.55 (dd,

1H, $J = 7.4, 11.3$ Hz, NOCHH), 4.73 (s, 1H, SiOCH), 5.78 (dd, 1H, $J = 4.1, 20.1$ Hz, SiCH=C), 5.99 (dd, 1H, $J = 4.1, 14.8$ Hz, SiC=CHH), 6.15 (dd, 1H, $J = 14.8, 20.1$ Hz, SiC=CHH), 6.8—7.4 (m, 4H, Ar-H); ^{13}C -NMR δ -2.2, -2.1, -0.1, 17.9, 35.6, 55.1, 70.7, 81.1, 87.1, 112.9, 127.2, 132.4, 133.0, 137.2, 158.6; exact mass, m/z 379.16299 (calcd for $\text{C}_{18}\text{H}_{29}\text{NO}_3\text{Si}_2$ m/z 379.16351); Anal. Calcd for $\text{C}_{18}\text{H}_{29}\text{NO}_3\text{Si}_2$: C, 56.95; H, 7.70. Found: C, 56.82; H, 7.71.

(1R*,5S*,8R*)-2-Dimethylvinylsiloxy-8-(2-furyl)-2-aza-3,7-dioxo-6-(dimethyl)silabicyclo[3.3.0]octane (2h). IR (film) 2962, 1915, 1726, 1254 cm^{-1} ; ^1H -NMR δ 0.14 (s, 3H, SiMe), 0.15 (s, 3H, SiMe), 0.32 (s, 3H, SiMe), 0.35 (s, 3H, SiMe), 2.37 (ddd, 1H, $J = 5.5, 8.2, 10.7$ Hz, SiCH), 4.06 (dd, 1H, $J = 5.5, 7.4$ Hz, NOCHH), 4.40 (dd, 1H, $J = 8.2, 8.5$ Hz, NCH), 4.46 (dd, 1H, $J = 7.4, 10.7$ Hz, NOCHH), 4.50 (d, 1H, $J = 8.5$ Hz, SiOCH), 5.71 (dd, 1H, $J = 4.4, 19.8$ Hz, SiCH=C), 5.93 (dd, 1H, $J = 4.4, 14.8$ Hz, SiC=CHH), 6.06 (dd, 1H, $J = 14.8, 19.8$ Hz, SiC=CHH), 6.3—7.4 (m, 3H, furyl); ^{13}C -NMR δ -2.7, -2.6, -2.4, 0.1, 1.0, 28.3, 69.9, 73.7, 82.9, 107.7, 110.1, 133.3, 136.5, 142.5, 153.8.

(1R*,5S*,8R*)-2-Dimethylvinylsiloxy-8-(2-furyl)-1-methyl-2-aza-3,7-dioxo-6-(dimethyl)silabicyclo[3.3.0]octane (2i). IR (film) 2958, 1919, 1647, 1254 cm^{-1} ; ^1H -NMR δ 0.20 (s, 3H, SiMe), 0.22 (s, 3H, SiMe), 0.32 (s, 3H, SiMe), 0.39 (s, 3H, SiMe), 1.07 (s, 3H, Me), 1.84 (dd, 1H, $J = 5.8, 11.3$ Hz, SiCH), 4.03 (dd, 1H, $J = 5.8, 7.7$ Hz, NOCHH), 4.52 (dd, 1H, $J = 7.7, 11.3$ Hz, NOCHH), 4.68 (s, 1H, SiOCH), 5.77 (dd, 1H, $J = 4.1, 20.1$ Hz, SiCH=C), 5.98 (dd, 1H, $J = 4.1, 14.8$ Hz, SiC=CHH), 6.16 (dd, 1H, $J = 14.8, 20.3$ Hz, SiC=CHH), 6.2—7.4 (m, 3H, furyl); ^{13}C -NMR δ -2.4, -2.3, 0.0, 18.0, 35.4, 70.4, 77.6, 87.0, 107.0, 109.9, 133.0, 137.1, 141.6, 153.2; exact mass, m/z 339.13186 (calcd for $\text{C}_{15}\text{H}_{25}\text{NO}_3\text{Si}_2$ m/z 339.13221); Anal. Calcd for $\text{C}_{15}\text{H}_{25}\text{NO}_3\text{Si}_2$: C, 53.06; H, 7.42. Found: C, 53.18; H, 7.36.

General procedure for *O*-diphenylvinylsilylation of 2-nitroalkanols (3).

To a solution of 2-nitroalkanol (**1**) in THF (1.5 mL/1 mmol of **1**) were added chlorodiphenylvinylsilane (1.0 equiv) and imidazole (2.0 equiv) at 0 °C. The resulting white suspension was stirred at 0 °C for 1 h. The reaction was quenched with H_2O and extracted with AcOEt (3 times). The combined organic layers were dried over MgSO_4 , filtered, and concentrated under reduced pressure. The residue was purified by CC to afford *O*-(diphenylvinylsilyl)-2-nitroalkanols (**3**).

General procedure for intramolecular cycloaddition of *O*-(diphenylvinylsilyl)-2-nitroalkanol (3).

To a solution of *O*-(diphenylvinylsilyl)-2-nitroalkanols **3** in CH_3CN (10 mL/1 mmol of **3**) were added Et_3N (2.0 equiv) and chlorotrimethylsilane (1.5 equiv) at 0 °C. The reaction mixture was stirred at 0 °C for 30 min, then at rt until the disappearance of **3** by an NMR diagnosis for a small

aliquot of the reaction mixture. The reaction was quenched with H₂O and extracted with hexane/AcOEt (3 : 1) (2 times). The combined organic layers, which showed a single spot on TLC, were dried over MgSO₄, filtered, and concentrated by a rotary evaporator, then an oil rotary pump under high vacuum to give a cycloadduct (**4**). Thus-obtained cycloadducts were stable enough for column chromatography over silica gel (Merck silica gel 60 7734) using hexane/EtOAc. Fortunately, no further purification by silica gel chromatography was necessary for thus-obtained **4** because of its very high purity as verified by an NMR spectroscopy.

(1*R,5*S**,8*R**)-8-Isopropyl-2-trimethylsiloxy-2-aza-3,7-dioxo-6-(diphenyl)silabicyclo-[3.3.0]octane (4a).** IR (film) 2961, 1429, 1251, 1120 cm⁻¹; ¹H-NMR δ 0.19 (s, 9H, SiMe₃), 1.01 (d, 3H, *J* = 6.6 Hz, *Me*), 1.06 (d, 3H, *J* = 6.9 Hz, *Me*), 1.8—2.0 (m, 1H, Me₂CH), 2.73 (ddd, 1H, *J* = 5.5, 8.5, 11.0 Hz, SiCH), 3.66 (dd, 1H, *J* = 4.9, 8.2 Hz, SiOCH), 3.87 (dd, 1H, *J* = 5.5, 7.4 Hz, NOCHH), 4.11 (dd, 1H, *J* = 8.2, 8.5 Hz, NCH), 4.35 (dd, 1H, *J* = 7.4, 11.0 Hz, NOCHH), 7.4—7.7 (m, 10H, Ar-H); ¹³C-NMR δ -0.4, 17.2, 19.2, 28.3, 33.4, 69.8, 82.5, 85.0, 128.0, 128.1, 130.5, 132.1, 134.2, 134.4, 134.8; exact mass, *m/z* 413.18456 (calcd for C₂₂H₃₁NO₃Si₂ *m/z* 413.18425); Anal. Calcd for C₂₂H₃₁NO₃Si₂: C, 63.88; H, 7.55. Found: C, 63.71; H, 7.54.

(1*R,5*S**,8*R**)-8-Pentyl-2-trimethylsiloxy-2-aza-3,7-dioxo-6-(diphenyl)silabicyclo-[3.3.0]octane (4b).** IR (film) 1429, 1251, 1120 cm⁻¹; ¹H-NMR δ 0.20 (s, 9H, SiMe₃), 0.90 (t, 3H, *J* = 6.9 Hz, *Me*), 1.2—1.8 (m, 8H, CH₃(CH₂)₄), 2.73 (ddd, 1H, *J* = 5.8, 8.2, 11.0 Hz, SiCH), 3.79 (m, 1H, SiOCH), 3.86 (dd, 1H, *J* = 5.8, 7.4 Hz, NOCHH), 3.96 (dd, 1H, *J* = 8.2, 8.8 Hz, ONCH), 4.36 (dd, 1H, *J* = 7.4, 11.0 Hz, NOCHH), 7.3—7.8 (m, 10H, Ar-H); ¹³C-NMR δ -0.5, 14.1, 22.6, 25.4, 28.1, 31.9, 37.2, 69.9, 80.4, 85.1, 128.1, 130.5, 131.9, 134.4, 134.7, 135.4.

(1*R,5*S**,8*R**)-1-Methyl-8-pentyl-2-trimethylsiloxy-2-aza-3,7-dioxo-6-(diphenyl)silabicyclo[3.3.0]octane (4c).** IR (film) 2956, 1250, 1120 cm⁻¹; ¹H-NMR δ 0.18 (s, 9H, SiMe₃), 0.9—1.8 (m, 11H, C₅H₁₁), 1.31 (s, 3H, *Me*), 2.28 (dd, 1H, *J* = 6.1, 11.5 Hz, SiCH), 3.7—3.9 (m, 2H, NOCHH, C₅H₁₁CH), 4.42 (dd, 1H, *J* = 7.7, 11.5 Hz, NOCHH), 7.3—7.7 (m, 10H, Ar-H); ¹³C-NMR δ -0.36, 14.1, 16.4, 22.7, 26.9, 32.1, 32.7, 35.2, 70.6, 82.7, 86.0, 128.1, 130.3, 130.5, 132.4, 133.5, 134.6; exact mass, *m/z* 455.23101 (calcd for C₂₅H₃₇NO₃Si₂ *m/z* 455.23120); Anal. Calcd for C₂₅H₃₇NO₃Si₂: C, 65.89; H, 8.18. Found: C, 65.77; H, 8.09.

(1*R,5*S**,8*R**)-2-Trimethylsiloxy-8-phenyl-2-aza-3,7-dioxo-6-(diphenyl)silabicyclo[3.3.0]-octane (4d).** IR (film) 1429, 1251, 1120 cm⁻¹; ¹H-NMR δ 0.08 (s, 9H, SiMe₃), 2.86 (ddd, 1H, *J* = 6.0, 8.5, 11.3 Hz, SiCH), 3.97 (dd, 1H, *J* = 6.0, 7.4 Hz, NOCHH), 4.17 (dd, 1H, *J* = 8.5, 8.8 Hz, NCH), 4.44 (d, 1H, *J* = 7.4, 11.3 Hz, NOCHH), 4.85 (d, 1H, *J* = 8.8 Hz, PhCH), 7.2—7.8 (m, 15H, Ar-H); ¹³C-NMR δ -0.6, 28.4, 70.1, 81.3, 87.6, 125.6, 127.5, 128.2, 128.3, 130.7, 130.8, 131.4, 133.4, 134.5, 134.7, 142.9; exact mass, *m/z* 447.16849 (calcd for C₂₅H₂₉NO₃Si₂ *m/z* 447.16860);

Anal. Calcd for $C_{25}H_{29}NO_3Si_2$: C, 67.07; H, 6.53. Found: C, 67.15; H, 6.49.

(1R*,5S*,8R*)-1-Methyl-2-trimethylsiloxy-8-phenyl-2-aza-3,7-dioxa-6-(diphenyl)silabicyclo[3.3.0]octane (4e). IR (film) 2960, 1429, 1250, 1115, 1045, 879 cm^{-1} ; 1H -NMR δ 0.15 (s, 9H, $SiMe_3$), 0.92 (s, 3H, Me), 2.46 (dd, 1H, $J = 6.1, 11.3$ Hz, $SiCH$), 3.99 (dd, 1H, $J = 6.1, 7.7$ Hz, $NOCHH$), 4.54 (dd, 1H, $J = 7.7, 11.3$ Hz, $NOCHH$), 5.18 (s, 1H, $PhCH$), 7.2—7.8 (m, 15H, Ar-H); ^{13}C -NMR δ -0.36, 18.0, 35.1, 70.8, 83.1, 87.5, 126.2, 127.1, 127.6, 128.2, 130.5, 130.6, 132.2, 133.4, 134.4, 134.6, 140.2.

(1R*,5S*,8R*)-8-(4-Methoxyphenyl)-2-trimethylsiloxy-2-aza-3,7-dioxa-6-(diphenyl)silabicyclo[3.3.0]octane (4f). IR (film) 1429, 1249, 1120 cm^{-1} ; 1H -NMR δ 0.07 (s, 9H, $SiMe$), 2.84 (ddd, 1H, $J = 6.0, 8.2, 11.0$ Hz, $SiCH$), 3.81 (s, 3H, OMe), 3.95 (dd, 1H, $J = 6.0, 7.4$ Hz, $NOCHH$), 4.14 (dd, 1H, $J = 8.2, 8.8$ Hz, NCH), 4.43 (dd, 1H, $J = 7.4, 11.0$ Hz, $NOCHH$), 4.79 (d, 1H, $J = 8.8$ Hz, $SiOCH$), 6.8—7.8 (m, 14H, Ar-H); ^{13}C -NMR δ -0.6, 28.4, 55.3, 70.2, 81.0, 87.6, 113.7, 126.9, 127.7, 128.2, 129.6, 130.6, 130.7, 131.6, 133.5, 134.5, 134.7, 135.1, 159.0; exact mass, m/z 477.17902 (calcd for $C_{26}H_{31}NO_4Si_2$ m/z 477.17916); Anal. Calcd for $C_{26}H_{31}NO_4Si_2$: C, 65.37; H, 6.54. Found: C, 65.44; H, 6.51.

Hydrogenolysis of N—OTMS bond in cycloadducts (4) and formation of N—Boc bond. The following description for 4a is representative.

(1R*,5S*,8R*)-8-Isopropyl-2-tert-butoxycarbonyl-2-aza-3,7-dioxa-6-(diphenyl)silabicyclo[3.3.0]octane (6a). To a black suspension of Pd-C (150 mg) in AcOEt (2 mL) were added a solution of **4a** (224 mg, 0.542 mmol) and $(Boc)_2O$ (237 mg, 2.0 equiv) in AcOEt (3 mL). The mixture was stirred for 45 h at room temperature under H_2 atmosphere and filtered through a celite pad. The pad was rinsed with several portions of AcOEt. The combined filtrates and washings were concentrated by a rotary evaporator to give a crude product, which was purified by CC (hexane/EtOAc = 20:1) affording **6a** (136 mg, 59%): 1H -NMR δ 1.05 (d, 3H, $J = 6.9$ Hz, Me), 1.09 (d, 3H, $J = 6.9$ Hz, Me), 1.50 (s, 9H, $tert$ -Bu), 1.9—2.1 (m, 1H, Me_2CH), 2.49 (ddd, 1H, $J = 5.0, 9.1, 9.9$ Hz, $SiCH$), 3.8—4.0 (m, 3H, $SiOCH$, $NOCH_2$), 4.82 (dd, 1H, $J = 7.4, 9.1$ Hz, NCH), 7.4—7.7 (m, 10H, Ar-H). Because of instability of this compound, **6a** was subjected to subsequent transformation immediately after an 1H NMR measurement.

(1R*,5S*,8R*)-8-Pentyl-2-tert-butoxycarbonyl-2-aza-3,7-dioxa-6-(diphenyl)silabicyclo[3.3.0]octane (6b). This compound (172 mg, 42%) was prepared in the similar way as that for **6a**. 1H -NMR δ 0.8—1.8 (m, 20 H, C_5H_{11} , Boc), 2.51 (ddd, 1H, $J = 5.2, 9.1, 9.6$ Hz, $SiCH$), 3.91 (dd, 1H, $J = 5.2, 8.0$ Hz, $NOCHH$), 4.00 (dd, 1H, $J = 8.0, 9.6$ Hz, $NOCHH$), 4.05—4.16 (m, 1H, $C_5H_{11}CH$), 4.63 (dd, 1H, $J = 6.6, 9.1$ Hz, NCH), 7.4—7.8 (m, 10H, Ar-H).

General procedure for Tamao oxidation and subsequent acetylation

To a solution of **6** in THF and MeOH (1:1) (6 mL/1 mmol of **6**) were added potassium hydrogen carbonate (2.0 equiv) and potassium fluoride (3.0 equiv) at rt followed by the addition of 30 % hydrogen peroxide (1.5 equiv) in one portion. The mixture was stirred at rt for 30 min and the remaining hydrogen peroxide is decomposed by the careful dropwise addition of an aqueous saturated solution of sodium thiosulfate pentahydrate. The mixture was extracted with three portions of AcOEt. The combined extracts were dried over MgSO₄, filtered, and concentrated by a rotary evaporator to give a crude product. To a solution of this crude oxazolidinediol in THF were added Ac₂O (4 equiv), Et₃N (6 equiv), and DMAP (cat. amount) at rt. The reaction mixture was stirred at rt for 3 h, quenched with H₂O, and extracted with AcOEt. The combined organic solutions were dried over MgSO₄, filtered, and concentrated by a rotary evaporator to give an oil, which was purified by CC.

(3R*,4S*)-2-tert-Butoxycarbonyl-3-[(1S*)-1-acetoxy-2-methylpropyl]-4-acetoxyisoxazolidine (7). IR (film) 2965, 1759, 1704 cm⁻¹; ¹H-NMR δ 0.95 (d, 3H, *J* = 7.2 Hz, (CH₃)₂C), 0.97 (d, 3H, *J* = 7.1 Hz, (CH₃)₂C), 1.50 (s, 9H, ^tBuO), 2.02 and 2.05 (s, 6H, CH₃C=O), 2.0—2.3 (m, 1H, (CH₃)₂CH), 3.79 (dd, 1H, *J* = 4.4, 10.4 Hz, NOCHH), 3.94 (dd, 1H, *J* = 10.4 Hz, NOCHH), 4.46 (dd, 1H, *J* = 6.9, 9.9 Hz, NCH), 5.19 (dd, 1H, *J* = 2.2, 9.9 Hz, (CH₃)₂CCH), 5.59 (m, 1H, NOCCH); ¹³C-NMR δ 15.4, 20.4, 20.7, 20.9, 28.0, 29.7, 62.3, 74.2, 75.6, 76.0, 83.1, 158.0, 169.9, 170.3.

General procedure for reductive cleavage of isoxazolidines with molybdenum hexacarbonyl.

To a solution of isoxazolidine in CH₃CN-H₂O (10 : 1) (20 mL/1 mmol of isoxazolidine) was added Mo(CO)₆ (1.2 equiv) at rt. The mixture was heated under reflux for several hours. The crude reaction mixture was filtered through a short pad of silica gel. The pad was rinsed with several portions of AcOEt. The combined filtrates and washings were concentrated to give a residue, which was purified by CC (hexane/EtOAc = 1:1).

(2S*,3R*,4R*)-1,2,4-Tris(*O*-Acetyl)-3-(*N*-tert-butoxycarbonyl)amino-5-methylhexane-1,2,4-triol (8). IR (KBr) 2969, 1747, 1711, 1248 cm⁻¹; ¹H-NMR δ 0.89 (d, 3H, *J* = 6.9 Hz, Me), 0.93 (d, 3H, *J* = 6.9 Hz, Me), 1.44 (s, 9H, ^tBuOC=O), 1.96 (m, 1H, Me₂CH), 2.03 & 2.04 (s, 3H, CH₃C=O × 3), 3.98 (dd, 1H, *J* = 7.4, 11.5 Hz, AcOCHH), 4.14 (m, 1H, BocNCH), 4.24 (dd, 1H, *J* = 5.5, 11.5 Hz, AcOCHH), 4.66 (d, 1H, *J* = 10.4 Hz, BocNH), 4.76 (dd, 1H, *J* = 3.0, 9.6 Hz, Me₂CCH), 5.27 (m, 1H, AcOCCH); ¹³C-NMR δ 15.8, 19.8, 20.7, 20.8, 28.3, 28.6, 50.4, 62.7, 68.8, 74.7, 80.2, 155.1, 169.9, 170.5; exact mass, *m/z* 389.20480 (calcd for C₁₈H₃₁NO₈ *m/z* 389.20497); Anal. Calcd for C₁₈H₃₁NO₈: C, 55.51; H, 8.02. Found: C, 55.49; H, 8.19.

(3R*,4S*)-4-tert-Butyldimethylsiloxy-3-[(1R*)-1-tert-butyldimethylsiloxy]-2-(tert-butoxycarbonyl)isoxazolidine (9). To a solution of **6b** (74 mg, 0.26 mmol) in CH₂Cl₂ (3 mL) were added

Et₃N (0.18 mL) and TBSOTf (0.18 mL) at 0 °C. The mixture was stirred at that temperature for 1 h, then quenched with H₂O, and extracted with AcOEt. The combined organic solutions were dried over MgSO₄, filtered, and concentrated by a rotary evaporator to give a residual oil, which was purified by CC (hexane/EtOAc = 10:1) to give **9** (84 mg, 63 %); IR (film) 2960, 1714 cm⁻¹; ¹H-NMR δ 0.06 & 0.07 & 0.09 & 0.10 (s, 12H, SiMe), 0.89 & 0.91 (s, 18 H, Si-^tBu), 0.8—1.7 (m, 11H, C₅H₁₁), 1.47 (s, 9H, Boc), 3.71 (dd, 1H, *J* = 3.0, 8.8 Hz, NOCHH), 3.79 (dd, 1H, *J* = 6.1, 8.8 Hz, NOCHH), 3.95 (m, 1H, C₅H₁₁CH), 4.26 (dd, 1H, *J* = 1.9, 8.0 Hz, ONCH), 4.70 (ddd, 1H, *J* = 3.0, 6.1, 8.0 Hz, NOCCH); ¹³C-NMR δ -5.1, -4.9, -4.6, -4.1, 14.0, 17.9, 18.2, 22.6, 25.6, 26.0, 26.6, 28.2, 32.1, 32.9, 66.7, 71.5, 74.7, 75.9, 81.8, 158.0.

(2S*,3R*,4R*)-2,4-Bis(*tert*-Butyldimethylsiloxy)-3-(*N*-*tert*-butoxycarbonyl)aminononanal

(10). To a solution of **9** (131 mg, 0.25 mmol) in DMSO (5 mL) were added Et₃N (0.36 mL) and SO₃·Py (201 mg) at rt. The reaction mixture was stirred at rt for 11 h, then quenched with H₂O, and extracted with AcOEt/hexane (1 : 1). The combined organic solutions were dried over MgSO₄, filtered, and concentrated by a rotary evaporator to give a residual oil, which was purified by CC (hexane/EtOAc = 10:1) to give **10** (100 mg, 76 %); IR (film) 2929, 1716, 1495 cm⁻¹; ¹H-NMR δ 0.05 & 0.07 & 0.08 & 0.10 (s, 12H, SiMe), 0.88 & 0.92 (s, 18H, Si-^tBu), 0.8—1.9 (m, 11H, C₅H₁₁), 1.42 (s, 9H, Boc), 3.80 (m, 1H, C₅H₁₁CH), 4.01 (m, 1H, NCH), 4.20 (m, 1H, CHC=O), 4.96 (d, 1H, *J* = 9.3 Hz, BocNH), 9.62 (d, 1H, *J* = 1.1 Hz, CHO); ¹³C-NMR δ -4.8, -4.5, -4.4, -4.1, 14.0, 18.1, 18.3, 22.6, 25.1, 25.8 x 2, 28.3, 31.8, 32.0, 34.4, 56.2, 74.2, 77.9, 79.5, 155.0, 202.4.

(3S*,4R*,5R*)-2,3-Diacetoxy-4-(*N*-*tert*-butoxycarbonyl)amino-5-pentyltetrahydrofuran

(11). To a solution of **10** (100 mg, 0.19 mmol) in THF (5 mL) was added TBAF (0.42 mL) at 0°C. The mixture was stirred at rt for 3 h, quenched with H₂O, and extracted with AcOEt. The combined organic solutions were dried over MgSO₄, filtered, and concentrated by a rotary evaporator to give a residual oil, which was purified by CC (hexane/EtOAc = 1:1) to give a lactol (35 mg, 0.12 mmol, 63 %). This lactol was acetylated in a usual way as shown above to give **11** (38 mg, 82 %); IR (film) 2933, 1759, 1716, 1699, 1525 cm⁻¹; ¹H-NMR δ (major isomer) 0.8—1.8 (m, 11H, C₅H₁₁), 1.44 (s, 9H, *t*-BuO), 2.09 (s, 6H, AcO), 3.8—4.1 (m, 2H, BocNCH, C₅H₁₁CH), 4.82 (d, 1H, *J* = 8.5 Hz, BocNH), 5.02 (d, 1H, *J* = 2.5 Hz, NCCHOAc), 6.11 (s, 1H, OCHOAc); ¹³C-NMR δ (major isomer) 14.0, 20.8, 21.1, 22.5, 25.0, 28.3, 31.6, 33.6, 75.1, 80.3, 81.8, 85.2, 99.2, 154.8, 169.2; exact mass, *m/z* 373.21022 (calcd for C₁₈H₃₁NO₇ *m/z* 373.21005); Anal. Calcd for C₁₈H₃₁NO₇: C, 57.89; H, 8.37. Found: C, 57.66; H, 8.33.

4.39 ppm

3.98 ppm

3.33 ppm

19 crude

Pulse Sequence: szpul

29 crude

Pulse Sequence: szpul

34 crude

Pulse Sequence: szpul

S22

4.3 crude

Pulse Sequence: szpul

S24

7.38 7.35 ppm

ppm

ppm

44 crude

Pulse Sequence: szpul

S26

131 crude

Pulse Sequence: szpul

4a

Pulse Sequence: szpul

S30

4c

Pulse Sequence: s2pul

S34

172 crude

Pulse Sequence: szpul

S38

135

Pulse Sequence: szpul

168

Pulse Sequence: szpul

S42

Pulse Sequence: s2puls

77-A

Pulse Sequence: s2pu1

11