Supplementary Information

**Chelating Diamide Based Rate Enhancement of Intramolecular
Alkene Hydroaminations Catalyzed by a Neutral Sc(III) Complex**

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Table of Contents

Experimental procedure and data of compounds: S2-S11

References: S12

Selected spectra: S13-S23

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General information

Melting points were obtained using a Mel-Temp II apparatus equipped with a digital thermometer and are uncorrected. High Resolution Mass spectra were obtained on a Bruker MicroTOF spectrometer.

^1H NMR spectra were recorded on a Bruker AVANCE DPX-300 (300MHz), or AVANCE DPX-500 (500MHz) spectrometer. Chemical shifts are reported in ppm from tetramethylsilane with the residual protic solvent resonance as the internal standard (chloroform: δ 7.24 ppm, or benzene: δ 7.16 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplets, br s = broad singlet, br d = broad doublet, br m = broad multiplet), integration, coupling constants (in Hz), and assignments. ^{13}C NMR spectra were recorded on a Bruker AVANCE DPX-300 (300MHz), or AVANCE DPX-500 (500MHz) spectrometer with complete decoupling. Chemical shifts are reported in ppm from tetramethylsilane with the solvent as the internal standard (CDCl_3 : δ 77.0 ppm).

Analytical thin layer chromatography was performed on Polygram[®] SIL G/UV₂₅₄ 1.25 mm silica gel plates with a fluorescent indicator. Flash chromatography was performed on Merck silica gel 60. Solvents for extraction and flash chromatography were reagent grade.

All experiments were carried out under an argon atmosphere using standard anaerobic methods. Organoscandium complexes were manipulated under an argon atmosphere in a glove box. Benzene- D_6 and aminoalkenes were distilled from Na and CaH_2 respectively, under an argon atmosphere, and stored at $-30\text{ }^\circ\text{C}$ in a glove box. Aminoalkenes¹, 1-amino-2,2-dimethyl-4-pentene (**2a**), 2-amino-5-hexene (**2b**), 1-amino-2-methyl-4-pentene (**2c**), 1-amino-2-phenyl-4-pentene (**2d**), 5-amino-1,8-nonadiene (**2f**), and proligands², *N,N'*-bis(2-isopropylphenyl)ethane-1,2-diamine (**6**), *N,N'*-bis(*P,P*-diisopropylthiophosphinyl)-2,2-dimethyl-1,3-propanediamine (**4**) were prepared according to reported procedures.

General Procedure for Intramolecular Alkene Hydroaminations

In an argon-filled glove box, $\text{Sc}[\text{N}(\text{TMS})_2]_3$ (**1a**) (10.5 mg, 0.02 mmol), bis(isopropylphenylamino)ethylene diamine proligand **6** (5.9 mg, 0.02 mmol), C_6D_6 (0.7 mL) were introduced sequentially into a J. Young NMR tube equipped with Teflon screw cap. The homogeneous reaction mixture was maintained at 120 °C in a constant temperature oil bath until ligand attachment was judged complete by the disappearance of the $\text{Sc}[\text{N}(\text{TMS})_2]_3$ resonance in the ^1H NMR spectrum with concomitant production of $(\text{TMS})_2\text{NH}$. To the resulting complex was added the appropriate aminoalkene **2** (0.4 mmol) and the reaction mixture was subsequently heated at 60 °C or 120 °C in an oil bath to achieve hydroamination. ^1H NMR spectroscopy using a pulse delay of 10 sec was employed to monitor the progress of the reaction.

Preparative Scale Hydroaminations

2,5-Dimethylpyrrolidine·HCl salt

In an argon-filled glove box, $\text{Sc}[\text{N}(\text{TMS})_2]_3$ (**1a**) (44.5 mg, 0.15 mmol) and *N,N'*-bis(2-isopropylphenyl)ethane-1,2-diamine (**5**) (78.9 mg, 0.15 mmol) were introduced into a 30 mL sealed tube equipped with a magnetic stirring bar and degassed benzene (6.6 mL) was subsequently added. The flask was sealed and the homogeneous reaction mixture was heated at 120 °C with stirring for 2 h to effect ligand attachment. The reaction mixture was cooled to room temperature and 2-amino-5-hexene (**2a**) (0.3 g, 0.38 mL, 3 mmol) was added via micro syringe, in the glove box. The reaction mixture was then heated to 60 °C in an oil bath with stirring for 3 h to complete hydroamination. The product amine and solvent were subsequently separated from the catalyst by vacuum transfer and the resultant mixture was cautiously added at -15 °C to a 6 M solution of HCl in diethyl ether (15 mL). Removal of the solvents *in vacuo* provided the title compound (0.4 g, 98%) as a white solid.

The ^1H and ^{13}C NMR spectra are identical to the reported data.³

^1H NMR (CDCl_3 , 500 MHz): (*trans* only) δ ppm 9.54 (br s, 2H, $=\text{NH}_2^+\text{Cl}^-$), 3.79 (m, 2H, CH), 2.18 (m, 1H, CHH), 1.66 (m, 2H, CHH), 1.49 (d, 6H, $-\text{CH}_3$, $J=7.0$ Hz).

^{13}C NMR (CDCl_3 , 500 MHz): (*trans*) δ ppm 54.8, 32.3, 18.2.

Syntheses of Aminoalkenes and Its Derivatives

1-Amino-2,2-dimethyl-4-pentene (2a)

To a stirred suspension of LiAlH_4 (2.66 g, 70 mmol) in dry Et_2O (60 mL) was added 2,2-dimethylpent-4-ene-1-nitrile (3.8 g, 35 mmol)¹ dropwise at ambient temperature. After heating at reflux overnight, the reaction mixture was cooled to 0 °C and carefully quenched via sequential addition of H_2O (2 mL), 15% aqueous NaOH (2 mL) and H_2O (4 mL). The mixture was subsequently stirred at room temperature for 2 h and anhydrous MgSO_4 (4 g) was added. The suspension was filtered and extracted 3 times with diethyl ether (15 mL). The filtrate was concentrated *in vacuo* and the residue was distilled to afford 3.5 g (89 %) of the title compound **2a** (bp = 51-52 °C).

^1H NMR (CDCl_3 , 500 MHz): δ ppm 5.73-5.79 (m, 1H, $\text{CH}=\text{CH}_2$), 4.98-5.08 (m, 2H, $\text{CH}=\text{CH}_2$), 2.45 (s, 2H, NCH_2), 1.99 (d, 2H, $\text{CH}_2\text{CH}=\text{}$, $J_{\text{HH}} = 7.6$ Hz), 1.16 (br s, 2H, NH_2), 0.88 (s, 6H, Me_2).

^{13}C NMR (CDCl_3 , 500 MHz): δ ppm 135.9, 117.1, 53.1, 44.6, 36.1, 23.9.

2-Amino-5-hexene (2b)

To a suspension of LiAlH_4 (2.07 g, 47 mmol) in 60 mL of dry Et_2O at 0 °C was added dropwise hex-5-en-2-one oxime^{2a} (3 g, 26.5 mmol). After refluxing for 3 h, the

reaction mixture was cooled to 0 °C and carefully quenched via sequential addition of H₂O (2 mL), 15% aqueous NaOH (2 mL) and H₂O (4 mL). The mixture was stirred at room temperature for 2 h, and anhydrous MgSO₄ (5 g) was added. The suspension was filtered. The filtered cake was washed with Et₂O and concentrated by distillation using a Vigreux column. The residue was purified by distillation at 92-93 °C to afford 1.66g (63%) of title compound **2b**.

¹H NMR (CDCl₃, 300 MHz): δ ppm 5.79 (m, 1H, -CH=), 4.98 (br d, 1H, =CHH, *J*=17.1 Hz), 4.92 (br d, 1H, =CHH, *J*=10.2 Hz), 2.87 (m, 1H, CH), 2.07 (m, 2H, CH₂), 1.38 (m, 2H, CH₂), 1.16 (br s, 2H, NH), 1.03 (d, 3H, CH₃, *J*=6.3 Hz).

¹³C NMR (CDCl₃, 300 MHz): δ ppm 138.6, 114.4, 46.4, 39.2, 30.7, 23.9.

1-Amino-2-methyl-4-pentene (2c)

This compound was prepared as described for **2a** utilizing 2-methylpent-4-ene-1-nitrile¹ (2.67 g, 28 mmol) and LiAlH₄ (2.1 g, 56 mmol) to give 1.5 g (54%) of **2c**. The product was purified by distillation at 100-101 °C.

¹H NMR (CDCl₃, 300 MHz): δ ppm 5.76 (m, 1H, -CH=), 5.00 (m, 2H, =CH₂), 2.61 (dd, 1H, NCHH, *J*=12.6, 6.0 Hz), 2.46 (dd, 1H, NCHH, *J*=12.6, 6.9 Hz), 2.11 (m, 1H, CHH), 1.87 (m, 1H, CHH), 1.53 (m, 1H, CH), 1.27 (br s, 2H, NH₂), 0.88 (d, 3H, CH₃, *J*=6.6Hz).

¹³C NMR (CDCl₃, 500 MHz): δ ppm 137.1, 115.8, 47.9, 38.9, 36.2, 17.3.

1-Amino-2-phenyl-4-pentene (2d)

This compound was prepared according to the procedure as described for **2a**, utilizing 2-phenylpent-4-ene-1-nitrile¹ (3 g, 19 mmol) and LiAlH₄ (1.4 g, 38 mmol) to give 1.85 g (60%) of **2d**. The product was purified by distillation (bp = 203-204 °C).

^1H NMR (CDCl_3 , 300 MHz): δ ppm 7.25 (m, 5H, ArH), 5.67 (m, 1H, $-\text{CH}=\text{}$), 4.97 (br d, 1H, $=\text{CHH}$, $J=17.1$ Hz), 4.92 (bd, 1H, $=\text{CHH}$, $J=10.2$ Hz), 2.95 (dd, 1H, NCHH , $J=12.6$, 5.7 Hz), 2.83 (dd, 1H, NCHH , $J=12.6$, 8.7 Hz), 2.67 (quintet, 1H, $-\text{CH}-$), 2.36 (m, 2H, CH_2), 1.32 (br s, 2H, NH_2).

^{13}C NMR (CDCl_3 , 500 MHz): δ ppm 143.0, 136.6, 128.5, 127.9, 126.4, 116.0, 49.4, 47.4, 38.3.

Preparation of 6-Amino-10-methyl-1,9-undecadiene (2e)

6-Amino-10-methyl-1,9-undecadiene (**2e**) was prepared via 5 steps as described below (Scheme 1) utilizing 6-methyl-2-heptenone.

<Scheme 1>

N,N'-dimethyl-1-(10-methylundeca-1,9-dien-6-ylidene)hydrazine

To 6-Methyl-5-heptene-2-one (3.8 g, 4.4 mL, 30 mmol) was added *N,N'*-dimethylhydrazine (2.1 g, 2.7 mL, 35 mmol) at 0 °C and stirred for 3 h at room temperature. The mixture was concentrated and diluted with petroleum ether. The solution was dried over MgSO_4 and then filtered. The filtrate was concentrated to yield an oil which was shown to be pure by GC (a single peak, $R_t=6.43$ min, quantitative yield). The resulting hydrazone (3.56 g, 21.2 mmol) was dissolved in THF (100 mL) and *n*-BuLi (2.74 M solution, 8.5 mL, 23.3 mmol) was added at -15 °C. The mixture was stirred for 30 min at

-15 °C and 4-bromo-1-butene (2.35 mL, 23.3 mmol) was added dropwise at -15 °C. The reaction mixture was allowed to warm to room temperature and stirred overnight. H₂O (20 mL) was added to the mixture and aqueous layer was extracted with Et₂O (2 x 50 mL). The combined organic layers were washed with H₂O (30 mL) and dried over MgSO₄. The suspension was filtered and the filtrate was concentrated. The product was purified by vacuum distillation (bp = 57 °C at 0.05 mmHg) to give 4.62 g (98%) of pale yellow oil.

¹H NMR (CDCl₃, 500 MHz): δ ppm 5.73 (m, 1H, CH₂=CH), 5.03 (br m, 1H, Me₂C=CH), 4.91 (m, 2H, CH₂=), 2.36 (m, 2H, =CH-CH₂), 2.31 (s, 6H, -NMe₂), 2.16 (m, 4H, =C-(CH₂)₂), 2.02 (m, 2H, -CH₂-CH=), 1.59 (d, 3H, =CMe₂, *J*=7 Hz), 1.51 (d and m, mixed peak of =CMe₂ and -CH₂-, *J*=8 Hz).

¹³C NMR (CDCl₃, 500 MHz): δ ppm 171.8, 138.0, 131.8, 123.4, 114.8, 47.4, 35.6, 33.4, 29.4, 26.4, 25.7, 25.0, 17.6.

10-methyl-1,9-undecadiene-6-one oxime

To a solution of *N,N'*-dimethyl-1-(10-methylundeca-1,9-dien-6-ylidene)hydrazine (4.2 g, 18.8 mmol) and CH₂Cl₂ (50 mL) was added 10% aqueous HCl (60 mL) slowly at 0 °C and stirred overnight at room temperature. The mixture was separated and the aqueous layer was extracted with CH₂Cl₂ (2 x 80 mL). The combined organic layers were washed with NaHCO₃ saturated solution and dried over MgSO₄. The suspension was filtered and the filtrate was concentrated. The residue was subjected to column chromatography on silica gel (10% ethyl acetate in *n*-hexane) to give 3.2 g (94.4%) of 10-methyl-1,9-undecadiene-6-one as a colorless oil. The 10-methyl-1,9-undecadiene-6-one (3.5 g, 19.4 mmol) was dissolved in 42 mL of solvent (EtOH : THF : H₂O = 4 : 2 : 1) and hydroxylamine hydrochloride (2.7 g, 38.8 mmol) was added. To this reaction mixture was added NaHCO₃ (3.3 g, 38.8 mmol) slowly at 0 °C (exothermic) and stirred

overnight at room temperature. The suspension was filtered, the filter cake was extracted with EtOAc and the filtrate was diluted with EtOAc (80 mL). The solution was washed with H₂O (10 mL) and NaCl saturated solution. The organic layer was dried over MgSO₄ and the suspension was filtered. The filtrate was concentrated to give pure 3.44 g (91%) of the oxime as colorless oil.

¹H NMR (CDCl₃, 500 MHz): δ ppm 8.92 (br s, 1H, =N-OH), 5.78 (m, 1H, CH₂=CH), 5.11 (m, 1H, Me₂C=CH), 4.99 (m, 2H, CH₂=), 2.33 (br m, 2H, =CH-CH₂), 2.19 (m, 4H, =C-(CH₂)₂), 2.06 (app. sextet, 2H, -CH₂-CH=, J =7 Hz), 1.66 (s, 3H, =CMeMe), 1.51 (d and m, mixed peak of =CMeMe and -CH₂-, J_d =8.5 Hz).

¹³C NMR (CDCl₃, 500 MHz): δ ppm 161.3, 138.1, 132.5, 123.1, 114.9, 33.8, 33.3, 27.2, 25.3, 24.8, 24.1, 17.6.

6-Amino-10-methyl-1,9-undecadiene (2e)

To a suspension of LiAlH₄ (1.21 g, 31.8 mmol) in 80 mL of dry Et₂O was added 10-methyl-1,9-undecadiene-6-one oxime (3.1 g, 15.9 mmol) dropwise at -15 °C. After the addition was complete the reaction mixture was heated at reflux overnight. The reaction mixture was cooled to 0 °C and quenched via sequential addition of H₂O (7 mL), 10% aqueous NaOH (7 mL) and H₂O (15 mL). The mixture was stirred at ambient temperature for 30 min, filtered and the filter cake was extracted with Et₂O (15 mL). The combined organic layers were dried over anhydrous MgSO₄. The suspension was filtered and the filtrate was concentrated to give yellow oil. The residue was purified by vacuum distillation (bp = 42 °C at 0.02 mmHg) to afford 2.88g (99%) of compound **2e**.

¹H NMR (CDCl₃, 500 MHz): δ ppm 5.72 (m, 1H, CH₂=CH), 5.02 (br m, 1H, Me₂C=CH), 4.92 (dd, 1H, CHH=, J_1 =17, J_2 =2.5 Hz), 4.85 (dd, 1H, CHH=, J_1 =9.25 Hz, J_2 =1.25 Hz), 2.60 (m, 1H, NH₂CH), 1.95 (m, 4H, =CHCH₂ + Me₂C=CHCH₂), 1.56 (s, 3H, =CMeMe),

1.53 (s, 3H, =CMeMe), 1.35 (m, 4H, -CH₂-C(N)H-CH₂-), 1.19 (m, 2H, -CH₂-), 1.03 (br s, 2H, -NH₂).

¹³C NMR (CDCl₃, 500 MHz): δ ppm 138.7, 131.4, 124.3, 114.4, 50.7, 38.1, 37.5, 33.8, 25.6, 25.4, 24.7, 17.6.

HRMS : observed [MH⁺] = 182.1891, calculated [MH⁺] = 182.1903

5-Amino-1,8-nonadiene (2f)

This compound was prepared in a fashion analogous to **2b** utilizing nona-1,8-dien-5-one oxime (2.45g, 16 mmol), LiAlH₄ (1.25 g, 32 mmol) and Et₂O (70 mL) to give 1.5 g (67%) of **2f**.

¹H NMR (CDCl₃, 300 MHz): δ ppm 5.80 (m, 2H, -CH=), 5.01 (br d, 2H, =CHH, *J*=16.8 Hz), 4.93 (br d, 2H, =CHH, *J*=10.2 Hz), 2.72 (m, 1H, CH), 2.13 (m, 4H, CH₂), 1.50 (m, 2H, CH₂), 1.34 (m, 2H, CH₂), 1.18 (br s, 2H, NH₂) .

¹³C NMR (CDCl₃, 300 MHz): δ ppm 138.6, 114.5, 50.2, 37.2, 30.4.

N-(*p*-Tolylsulfonyl)-2-but-3-enyl-5-methylpyrrolidine (3f)

The reaction mixture, which was completely mono-cyclized to 2-but-3-enyl-5-methylpyrrolidine (0.4 mmol) using the catalyst Sc[N(TMS)₂]₃, was diluted with dried CH₂Cl₂ (2 mL) followed by addition of pyridine (97 μL, 1.2 mmol) and TsCl (114.4 mg, 0.6 mmol) at -15 °C. After stirring for 2 h, the reaction mixture was diluted with CH₂Cl₂ (10 mL) and washed with 1 N HCl (2 x 3 mL). The organic layer was dried over MgSO₄, filtered, and concentrated in vacuo. The residue was subjected to column chromatography on silica gel (5% EtOAc in *n*-hexane) to give 98.5 mg (84%) of title

compound **3f** as colorless solid. The ratio of *trans*:*cis* was determined by GC analysis to be 98:2.

¹H NMR (CDCl₃, 300 MHz): (only *trans*) δ ppm 7.65 (d, 2H, ArH, *J*=8.4 Hz), 7.18 (d, 2H, ArH, *J*=8.4 Hz), 5.68 (m, 1H, -CH=), 4.89 (m, 2H), 3.96 (quintet, 1H, NCH), 3.76 (m, 1H, NCH), 2.33 (s, 3H, CH₃), 1.95 (m, 5H), 1.60 (m, 1H), 1.45-1.20 (m, 2H), 1.10 (d, 3H, CH₃, *J*=6.3 Hz).

¹³C NMR (CDCl₃, 300 MHz): δ ppm 142.5, 139.6, 137.7, 129.3, 126.9, 114.8, 59.9, 56.3, 33.1, 31.4, 30.4, 27.7, 21.4, 20.9.

Syntheses of Proligands

N,N'-bis(*P,P*-diisopropylthiophosphinyl)-2,2-dimethyl-1,3-propanediamine (**4**)

To a solution of 2,2-dimethylpropane-1,2-diamine (0.3 g, 2.5 mmol) and *N,N*-diisopropylethylamine (1.96 mL, 11.25 mmol) in dichloromethane (7.5 mL) was added chlorodiisopropylphosphine (0.8 mL, 5 mmol) dropwise with stirring at 0 °C. The reaction mixture was allowed to reach 23 °C and stirred overnight under inert atmosphere. The resulting white precipitate was rapidly filtered with care being taken to minimize exposure to air and the filter cake was washed with dry methylene chloride (2 x 3 mL). Sulfur (0.17 g, 5.25 mmol) was then added in portions (exothermic) to the resulting mixture. The reaction mixture was heated to 80 °C with stirring for 30 min under argon. After cooling to ambient temperature, the mixture was concentrated in vacuo to give quantitative yield of **4** (mp = 143-144 °C).

^1H NMR (CDCl_3 , 300 MHz): δ ppm 2.86 (s, 4H, CH_2), 2.63 (br s, 2H, NH), 2.10 (m, 4H, CH), 1.17 (d, 12H, CH_3 , $J=6.9$ Hz), 1.16 (d, 12H, CH_3 , $J=6.9$ Hz).

^{13}C NMR (CDCl_3 , 300 MHz): δ ppm 46.9 36.9 (t, $J_{\text{c-p}}=6.0$ Hz), 30.2 (d, $J_{\text{c-p}}=61.6$ Hz), 23.6, 16.5, 16.2 (d, $J_{\text{c-p}}=2.7$ Hz).

^{31}P (CDCl_3 , 300 MHz): δ ppm 90.06.

***N,N'*-bis(2-isopropylphenyl)ethane-1,2-diamine (6)**

N,N'-Bis(2-isopropylphenyl)oxalamide² (2.0 g, 6.16 mmol) was reduced by addition to LiAlH_4 (0.47 g, 12.3 mmol) in THF (30 mL) at ambient temperature and then heating the resulting mixture at reflux overnight. The reaction mixture was cooled to 0 °C and carefully quenched via sequential addition of H_2O (0.5 mL), 15% aqueous NaOH (0.5 mL) and H_2O (1 mL). The mixture was stirred at room temperature for 2 h, and anhydrous MgSO_4 (1 g) was added. After filtration, the solvent was evaporated in vacuo. The residue was purified by preparative TLC on silica gel, using 20% ethyl acetate in *n*-hexane for elution, to afford the title compound (**6**) 1 g (55%) as a white solid (mp = 47-48 °C).

^1H NMR (CDCl_3 , 300 MHz): δ ppm 7.15 (m, 4H, ArH), 6.76 (m, 4H, ArH), 4.03 (bs, 2H, NH), 3.50 (s, 4H, CH_2), 2.85 (m, 2H, CH), 1.22 (d, 12H, CH_3 , $J=6.9$ Hz).

^{13}C NMR (CDCl_3 , 300 MHz): δ ppm 144.6, 132.8, 126.8, 125.1, 117.9, 110.8, 43.5, 27.2, 22.3.

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