PdCl₂-Catalyzed Efficient Transformation of Propargylic Amines to (*E*)- α -Chloroalkylidene- β -lactams

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The following compounds were prepared according to Typical Procedure I.

(1) *N*-(Non-4-yn-3-yl)amine (3b).

The reaction of **1b** (4.996 g, 35.7 mmol), phthalimide (5.789 g, 39.4 mmol), PPh₃ (10.291 g, 39.3 mmol), and diethyl azodicarboxylate (7.463 g, 42.9 mmol) afforded 8.15 g (85 %) of **2b**. Then the reaction of **2b** (8.15 g, 30.3 mmol) and 10 mL of NH₂NH₂·H₂O in 230 mL of absolute EtOH afforded 2.464 g (58 %) of **3b**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 3.60-3.50 (m, 1 H), 2.19 (t, *J* = 5.9 Hz, 2 H), 1.75-1.30 (m, 8 H), 0.99 (t, *J* = 7.4 Hz, 3 H), 0.91 (t, *J* = 6.9 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 83.3, 82.5, 50.0, 31.5, 30.9, 21.8, 18.3, 13.5, 10.3; MS (EI) *m/z* (%) 139 (M⁺, 0.10), 110 (100); IR (neat) 3369, 2235, 1595 cm⁻¹; HRMS (MALDI/DHB) calcd for C₉H₁₈N (M⁺+1) 140.1434. Found 140.1439.

(2) *N*-(2-Methylnon-4-yn-3-yl)amine (3c).

The reaction of **1c** (6.157 g, 40 mmol), phthalimide (6.468 g, 44 mmol), PPh₃ (11.528 g, 44 mmol), diethyl azodicarboxylate (8.596 g, 49.4 mmol) afforded 7.571 g (67 %) of **2c**. Then the reaction of **2c** (7.563 g, 26.7 mmol) and 10 mL of NH₂NH₂·H₂O in 250 mL of absolute EtOH afforded 2.172 g (53 %) of **3c**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 3.44-3.35 (m, 1 H), 2.19 (dt, *J* = 2.0 and 6.8 Hz, 2 H), 1.82-1.65 (m, 1 H), 1.60-1.31 (m, 6 H), 0.97 (d, *J* = 6.6 Hz, 6 H), 0.91 (t, *J* = 7.1 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 83.2, 81.8, 49.6, 34.5, 30.9, 21.8, 19.1, 18.2, 17.5, 13.5; MS (EI) *m/z* (%) 153 (M⁺, 0.19), 110 (100); IR (neat) 3376, 2237, 1598 cm⁻¹; HRMS (MALDI/DHB) calcd for C₁₀H₂₀N (M⁺+1) 154.1590. Found 154.1596.

(3) *N*-(1-Cyclohexyl-2-heptynyl)amine (3d).

The reaction of **1d** (5.038 g, 26 mmol), phthalimide (4.224 g, 28.7 mmol), PPh₃ (7.498 g, 28.6 mmol), diethyl azodicarboxylate (5.431 g, 31.2 mmol) afforded 5.141 g (61 %) of **2d**. Then the reaction of **2d** (5.129 g, 15.88 mmol) and 8 mL of NH₂NH₂·H₂O in 230 mL of absolute EtOH afforded 2.451 g (80 %) of **3d**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 3.43-3.30 (m, 1 H), 2.18 (dt, *J* = 1.7 and 6.3 Hz, 2 H), 1.91-1.56 (m,

5 H), 1.55-0.98 (m, 12 H), 0.91 (t, $J = 7.2$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 83.2, 82.3, 48.9, 44.4, 31.0, 29.6, 28.2, 26.4, 26.1, 26.0, 21.9, 18.3, 13.5; MS (EI) m/z (%) 194 ($\text{M}^+ + 1$, 12.48), 110 (100); IR (neat) 3374, 2228, 1595 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{13}\text{H}_{24}\text{N}$ ($\text{M}^+ + 1$) 194.1903. Found 194.1911.

(4) *N*-(1-Cyclohexyl-3-phenylpropargyl)amine (3e).

The reaction of **1e** (6.402 g, 30 mmol), phthalimide (4.857 g, 33 mmol), PPh_3 (8.653 g, 33 mmol), diethyl azodicarboxylate (6.270 g, 36 mmol) afforded **2e**. Then the reaction of above **2e** and 8 mL of $\text{NH}_2\text{NH}_2 \cdot \text{H}_2\text{O}$ in 230 mL of absolute EtOH afforded 2.973 g (47 %, two steps) of **3e**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.48-7.37 (m, 2 H), 7.36-7.23 (m, 3 H), 3.59 (d, $J = 5.4$ Hz, 1 H), 1.98-1.62 (m, 5 H), 1.62-1.39 (m, 2 H), 1.39-1.06 (m, 6 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 131.5, 128.1, 127.8, 123.3, 83.2, 49.3, 44.3, 29.7, 28.4, 26.4, 26.1, 26.0; MS (EI) m/z (%) 213 (M^+ , 1.37), 130 (100); IR (neat) 3374, 2221, 1598 cm^{-1} ; HRMS calcd for $\text{C}_{15}\text{H}_{19}\text{N}$ (M^+) 213.1518. Found 213.1500.

(5) *N*-(2-Methyl-7-phenylhept-4-yn-3-yl)amine (3f).

The reaction of **1f** (4.145 g, 20.5 mmol), phthalimide (3.330 g, 22.65 mmol), PPh₃ (5.909 g, 22.55 mmol), diethyl azodicarboxylate (4.310 g, 24.77 mmol) afforded 4.548 g (67 %) of **2f**. Then the reaction of above **2f** (4.548 g, 13.74 mmol) and 8 mL of NH₂NH₂·H₂O in 200 mL of absolute EtOH afforded 2.061 g (75 %) of **3f**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.35-7.15 (m, 5 H), 3.35 (dt, *J* = 2.1 and 5.4 Hz, 1 H), 2.81 (t, *J* = 7.5 Hz, 2 H), 2.48 (dt, *J* = 2.1 and 7.5 Hz, 2 H), 1.79-1.60 (m, 1 H), 1.46 (bs, 2 H), 0.93 (d, *J* = 6.9 Hz, 3 H), 0.92 (d, *J* = 6.9 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 140.7, 128.4, 128.2, 126.1, 82.6, 82.5, 49.6, 35.2, 34.4, 20.8, 19.1, 17.5; MS (EI) *m/z* (%) 202 (*M*⁺+1, 3.03), 158 (100); IR (neat) 3374, 2235, 1603 cm⁻¹; HRMS calcd for C₁₁H₁₂N (*M*⁺-C₃H₇) 158.0970. Found 158.0971.

(6) *N*-(2,6,6-Trimethylhept-4-yn-3-yl)amine (3g).

The reaction of **1g** (3.776 g, 24.5 mmol), phthalimide (3.968 g, 26.95 mmol), PPh₃ (7.068 g, 26.95 mmol), diethyl azodicarboxylate (5.153 g,

29.6 mmol) afforded 5.359 g (67 %) of **2g**. Then the reaction of above **2g** (5.359 g, 18.9 mmol) and 8 mL of $\text{NH}_2\text{NH}_2 \cdot \text{H}_2\text{O}$ in 200 mL of absolute EtOH afforded 1.183 g (41 %) of **3g**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 3.37 (d, $J = 5.7$ Hz, 1 H), 1.81-1.65 (m, 1 H), 1.41 (bs, 2 H), 1.21 (s, 9 H), 0.97 (d, $J = 3.6$ Hz, 6 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 91.7, 80.2, 49.4, 34.6, 31.1, 27.2, 19.2, 17.4; MS (EI) m/z (%) 152 ($\text{M}^+ - 1$, 0.88), 110 (100); IR (neat) 3375, 2228, 1597 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{10}\text{H}_{20}\text{N}$ ($\text{M}^+ + 1$) 154.1590. Found 154.1599.

The following compounds were prepared according to Typical Procedure II.

(1) *N*-(Non-4-yn-3-yl)-*N*-benzylamine (4b**).**

The reaction of **3b** (692 mg, 4.98 mmol), K_2CO_3 (721 mg, 5.22 mmol), and PhCH_2Br (934 mg, 5.46 mmol) afforded 525 mg (46 %) of **4b**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.46-7.20 (m, 5 H), 4.01 (d, $J = 12.9$ Hz, 1 H), 3.80 (d, $J = 12.9$ Hz, 1 H), 3.35-3.24 (m, 1 H), 2.24 (dt, $J = 1.9$ and 6.9 Hz, 2 H), 1.79-1.35 (m, 7 H), 1.00 (t, $J = 7.5$ Hz, 3 H), 0.93 (t, $J = 7.2$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 140.3, 128.4, 128.3, 126.9, 84.0, 81.1, 51.4, 51.0, 31.1, 29.3, 21.9, 18.4, 13.6, 10.5; MS (EI) m/z (%) 230 ($\text{M}^+ + 1$, 1.36), 200 ($\text{M}^+ - \text{C}_2\text{H}_5$, 73.33), 91 (100); IR (neat) 3309, 2235, 1604 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{16}\text{H}_{24}\text{N}$ ($\text{M}^+ + 1$) 230.1903. Found 230.1917.

(2) *N*-(2-Methylnon-4-yn-3-yl)-*N*-benzylamine (**4c**).

The reaction of **3c** (73 mg, 0.48 mmol), K₂CO₃ (74 mg, 0.54 mmol), and PhCH₂Br (120 mg, 0.71 mmol) afforded 88 mg (76 %) of **4c**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.45-7.18 (m, 5 H), 4.02 (d, *J* = 12.9 Hz, 1 H), 3.79 (d, *J* = 12.9 Hz, 1 H), 3.16 (dt, *J* = 1.6 and 3.7 Hz, 1 H), 2.24 (dt, *J* = 2.1 and 6.8 Hz, 2 H), 1.92-1.75 (m, 1 H), 1.60-1.38 (m, 4 H), 1.31 (bs, 1 H), 0.98 (d, *J* = 6.9 Hz, 6 H), 0.93 (t, *J* = 7.2 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 140.4, 128.3, 128.3, 126.8, 84.5, 79.7, 55.7, 51.6, 32.8, 31.1, 21.9, 19.7, 18.4, 17.8, 13.6; MS (EI) *m/z* (%) 243 (M⁺, 0.09), 242 (M⁺-1, 0.37), 200 (100); IR (neat) 3325, 2240, 1605 cm⁻¹; HRMS calcd for C₁₇H₂₅N (M⁺) 243.1982. Found 243.1980.

(3) *N*-(1-Cyclohexyl-2-heptynyl)-*N*-benzylamine (**4d**).

The reaction of **3d** (765 mg, 3.96 mmol), K₂CO₃ (575 mg, 4.17 mmol), and PhCH₂Br (763 mg, 4.46 mmol) afforded 715 mg (64 %) of **4d**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.48-7.15 (m, 5 H), 4.02 (d, *J* = 12.9 Hz, 1 H), 3.78 (d, *J* = 12.9 Hz, 1 H), 3.23-2.10 (m, 1 H), 2.24 (dt, *J* =

1.9 and 6.9 Hz, 2 H), 1.90-1.60 (m, 5 H), 1.60-1.36 (m, 5 H), 1.36-1.05 (m, 6 H), 0.94 (t, $J = 7.1$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 140.4, 128.3, 128.3, 126.8, 84.6, 80.2, 55.0, 51.6, 42.6, 31.2, 30.2, 28.5, 26.5, 26.2, 26.1, 21.9, 18.4, 13.6; MS (EI) m/z (%) 284 ($\text{M}^+ + 1$, 2.03), 283 (M^+ , 0.94), 200 (100); IR (neat) 3370, 2228, 1604 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{20}\text{H}_{30}\text{N}$ ($\text{M}^+ + 1$) 284.2373. Found 284.2372.

(4) *N*-(2-Methyl-7-phenylhept-4-yn-3-yl)-*N*-benzylamine (4f).

The reaction of **3f** (593 mg, 2.95 mmol), K_2CO_3 (421 mg, 3.05 mmol), and PhCH_2Br (606 mg, 3.54 mmol) afforded 606 mg (71 %) of **4f**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.45-7.14 (m, 10 H), 3.94 (d, $J = 13.1$ Hz, 1 H), 3.71 (d, $J = 13.1$ Hz, 1 H), 3.12 (dt, $J = 1.4$ and 3.6 Hz, 1 H), 2.84 (t, $J = 7.5$ Hz, 2 H), 2.55 (dt, $J = 1.8$ and 7.5 Hz, 2 H), 1.90-1.70 (m, 1 H), 1.31 (bs, 1 H), 0.94 (d, $J = 6.8$ Hz, 3 H), 0.93 (d, $J = 6.8$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 140.7, 140.3, 128.5, 128.3, 128.3, 128.2, 126.8, 126.2, 83.7, 80.6, 55.6, 51.5, 35.4, 32.7, 20.8, 19.7, 17.8; MS (EI) m/z (%) 292 ($\text{M}^+ + 1$, 1.31), 248 ($\text{M}^+ - \text{C}_3\text{H}_7$, 75.23), 91 (100); IR (neat) 3324, 2235, 1604 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{21}\text{H}_{26}\text{N}$ ($\text{M}^+ + 1$) 292.2060. Found 292.2044.

The following compounds were prepared according to Typical Procedure III.

(1) (*E*)- α -(1-Chloropentylidene)- β -ethyl- β -lactam (*E*)-**6b**).

The reaction of **3b** (139 mg, 1.0 mmol), PdCl₂ (9 mg, 0.05 mmol), CuCl₂ (268 mg, 1.99 mmol), and benzoquinone (112 mg, 1.04 mmol) was stirred at 45-50 °C for 8 h to afford 96 mg (48 %) of (*E*)-**6b**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 6.90 (bs, 1 H), 4.18 (dd, *J* = 3.2 and 7.4 Hz, 1 H), 2.85-2.65 (m, 2 H), 2.08-1.90 (m, 1 H), 1.77-1.52 (m, 3 H), 1.45-1.29 (m, 2 H), 0.96 (t, *J* = 7.4 Hz, 3 H), 0.93 (t, *J* = 7.5 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 162.7, 137.2, 136.7, 58.1, 34.5, 29.1, 24.6, 21.5, 13.7, 8.9; MS (EI) *m/z* (%) 203 (M⁺(³⁷Cl), 2.61), 201 (M⁺(³⁵Cl), 7.87), 81 (100); IR (neat) 3249, 1750, 1707 cm⁻¹; HRMS (MALDI/DHB) calcd for C₁₀H₁₇³⁵ClNO (M⁺+1) 202.0993. Found 202.1008.

(2) (*E*)- α -(1-Chloropentylidene)- β -(*i*-propyl)- β -lactam ((*E*)-6c):

The reaction of **3c** (148 mg, 0.97 mmol), PdCl₂ (9 mg, 0.051 mmol), CuCl₂ (267 mg, 1.98 mmol), and benzoquinone (110 mg, 1.02 mmol) was stirred at 45-50 °C for 8 h to afford 110 mg (53 %) of (*E*)-**6c**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 6.88 (bs, 1 H), 4.15 (d, *J* = 2.7 Hz, 1 H), 2.95-2.61 (m, 2 H), 2.36-2.12 (m, 1 H), 1.70-1.51 (m, 2 H), 1.50-1.28 (m, 2 H), 1.00 (d, *J* = 6.9 Hz, 3 H), 0.94 (d, *J* = 7.2 Hz, 3 H), 0.90 (d, *J* = 6.6 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 163.0, 136.7, 136.6, 62.4, 34.5, 29.1, 28.4, 21.5, 19.3, 15.4, 13.7; MS (EI) *m/z* (%) 217 (M⁺(³⁷Cl), 1.35), 215 (M⁺(³⁵Cl), 3.92), 172 (100); IR (neat) 3238, 1748, 1713 cm⁻¹; HRMS (MALDI/DHB) calcd for C₁₁H₁₉³⁵ClNO (M⁺+1) 216.1150. Found 216.1161.

(3) (*E*)- α -(1-Chloropentylidene)- β -cyclohexyl- β -lactam ((*E*)-6d):

The reaction of **3d** (151 mg, 0.78 mmol), PdCl₂ (7 mg, 0.04 mmol), CuCl₂ (215 mg, 1.59 mmol), and benzoquinone (89 mg, 0.82 mmol) was stirred at 45-50 °C for 8 h to afford 100 mg (50 %) of (*E*)-**6d**: solid, mp 100.5-102 °C (*n*-Hexane/Ethyl acetate); ¹H NMR (300 MHz, CDCl₃) δ 5.93 (bs, 1 H), 4.12 (d, *J* = 3 Hz, 1 H), 2.90-2.65 (m, 2 H), 1.98-1.52 (m, 9 H), 1.48-0.98 (m, 6 H), 0.93 (t, *J* = 7.4 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 163.0, 136.5, 136.3, 62.0, 38.2, 34.5, 29.9, 29.2, 26.14, 26.09, 25.9, 25.7, 21.5, 13.7; MS (EI) *m/z* (%) 257 (M⁺(³⁷Cl), 2.43), 255 (M⁺(³⁵Cl), 6.48), 172 (100); IR (KBr) 3205, 1741, 1703 cm⁻¹; Anal. Calcd for C₁₄H₂₂ClNO: C, 65.74; H, 8.67; N, 5.48. Found: C, 65.55; H, 8.38; N, 5.48.

Fig. 1. The X-ray structure of compound (*E*)-**6d**.

(4) (*E*)- α -(1-Chlorobenzylidene)- β -cyclohexyl- β -lactam ((*E*)-6e**).**

The reaction of **3e** (167 mg, 0.78 mmol), PdCl₂ (7 mg, 0.04 mmol), CuCl₂ (216 mg, 1.60 mmol), and benzoquinone (89 mg, 0.82 mmol) was stirred at 45-50 °C for 10.5 h to afford 69 mg (32 %) of (*E*)-**6e**: solid, mp 123-124 °C (*n*-Hexane/Ethyl acetate); ¹H NMR (300 MHz, CDCl₃) δ 8.05-7.90 (m, 2 H), 7.50-7.35 (m, 3 H), 6.92 (bs, 1 H), 4.22 (d, *J* = 3 Hz, 1 H), 2.22-1.95 (m, 1 H), 1.90-1.55 (m, 5 H), 1.45-0.95 (m, 5 H); ¹³C

NMR (75.4 MHz, CDCl_3) δ 161.3, 137.5, 133.6, 132.6, 130.3, 128.4, 128.1, 61.8, 37.8, 29.9, 26.3, 26.1, 25.7, 25.4; MS (EI) m/z (%) 277 ($\text{M}^+(\text{}^{37}\text{Cl})$, 3.40), 275 ($\text{M}^+(\text{}^{35}\text{Cl})$, 10.57), 192 (100); IR (KBr) 3198, 1736, 1657 cm^{-1} ; Anal. Calcd for $\text{C}_{16}\text{H}_{18}\text{ClNO}$: C, 69.68; H, 6.58; N, 5.08. Found: C, 69.58; H, 6.57; N, 5.10.

Fig. 2. The X-ray structure of compound (*E*)-**6e**.

(5) (*E*)- α -(1-Chloro-3-phenylpropylidene)- β -(*i*-propyl)- β -lactam ((*E*)-6f**).**

The reaction of **3f** (156 mg, 0.78 mmol), PdCl₂ (7 mg, 0.04 mmol), CuCl₂ (220 mg, 1.63 mmol), and benzoquinone (90 mg, 0.83 mmol) was stirred at 45-50 °C for 8 h to afford 86 mg (42 %) of **(E)-6f**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.38-7.15 (m, 5 H), 6.06 (bs, 1 H), 4.09 (d, *J* = 3.6 Hz, 1 H), 3.35-3.16 (m, 1 H), 3.10-2.85 (m, 3 H), 2.30-2.10 (m, 1 H), 0.92 (d, *J* = 6.8 Hz, 3 H), 0.70 (d, *J* = 6.8 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 162.6, 139.5, 137.4, 135.0, 128.5, 128.3, 126.1, 62.4, 36.0, 33.2, 28.3, 19.2, 15.1; MS (EI) *m/z* (%) 265 (M⁺(³⁷Cl), 4.58), 263 (M⁺(³⁵Cl), 13.83), 91(100); IR (neat) 3243, 1746, 1709 cm⁻¹; HRMS calcd for C₁₅H₁₈³⁵ClNO (M⁺) 263.1077. Found 263.1067.

The following compounds were prepared according to Typical Procedure IV.

(1) (E)-α-(1-Chloropentylidene)-β-(*n*-pentyl)-*N*-benzyl-β-lactam ((E)-6g).

The reaction of **4a** (143 mg, 0.53 mmol), PdCl₂ (5 mg, 0.028 mmol), CuCl₂ (148 mg, 1.10 mmol), and benzoquinone (62 mg, 0.57 mmol)

was stirred for 12 h at 45-50 °C to afford 108 mg (61 %) of **(E)-6g**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.41-7.20 (m, 5H), 4.74 (d, $J = 15.2$ Hz, 1 H), 4.15 (d, $J = 15.2$ Hz, 1 H), 4.07 (t, $J = 4.2$ Hz, 1 H), 2.91-2.65 (m, 2 H), 1.83-1.50 (m, 4 H), 1.48-1.06 (m, 8 H), 0.94 (t, $J = 7.4$ Hz, 3 H), 0.84 (t, $J = 6.9$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 161.8, 136.2, 135.7, 135.1, 128.7, 128.2, 127.7, 59.7, 44.7, 34.8, 31.6, 29.1, 23.5, 22.4, 21.5, 13.9, 13.7; MS (EI) m/z (%) 334 ($\text{M}^+ - 1(^{37}\text{Cl})$, 0.97), 332 ($\text{M}^+ - 1(^{35}\text{Cl})$, 1.87), 91 (100); IR (neat) 1747, 1707 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{20}\text{H}_{29}^{35}\text{ClNO}$ ($\text{M}^+ + 1$) 334.1932. Found 334.1953.

(2) (E)- α -(1-Chloropentylidene)- β -ethyl-N-benzyl- β -lactam ((E)-6h).

The reaction of **4b** (135 mg, 0.59 mmol), PdCl_2 (6 mg, 0.034 mmol), CuCl_2 (164 mg, 1.21 mmol), and benzoquinone (66 mg, 0.61 mmol) was stirred for 12 h at 45-50 °C to afford 134 mg (78 %) of **(E)-6h**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.41-7.20 (m, 5 H), 4.77 (d, $J = 15.2$ Hz, 1 H), 4.11 (d, $J = 15.2$ Hz, 1 H), 4.07 (d, $J = 3.9$ Hz, 1 H), 2.93-2.65 (m, 2 H), 1.93-1.68 (m, 2 H), 1.68-1.50 (m, 2 H), 1.46-1.28 (m, 2 H), 0.94 (t, $J = 7.2$ Hz, 3 H), 0.83 (t, $J = 7.5$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 161.8, 135.7, 135.6, 135.3, 128.7, 128.2, 127.7, 60.3, 44.5,

34.8, 29.2, 21.6, 21.5, 13.7, 7.8; MS (EI) m/z (%) 293 ($M^+({}^{37}\text{Cl})$, 3.12), 291 ($M^+({}^{35}\text{Cl})$, 9.77), 91 (100); IR (neat) 1748, 1717 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{17}\text{H}_{23}{}^{35}\text{ClNO}$ (M^++1) 292.1463. Found 292.1488.

(3) (*E*)- α -(1-Chloropentylidene)- β -cyclohexyl-*N*-benzyl- β -lactam ((*E*)-6j).

The reaction of **4d** (141 mg, 0.5 mmol), PdCl_2 (5 mg, 0.028 mmol), CuCl_2 (140 mg, 1.04 mmol), and benzoquinone (58 mg, 0.54 mmol) was stirred for 12 h at 45-50 $^\circ\text{C}$ to afford 108 mg (63 %) of (*E*)-**6j**: liquid; ^1H NMR (300 MHz, CDCl_3) δ 7.43-7.18 (m, 5 H), 4.84 (d, $J = 15.3$ Hz, 1 H), 4.11 (d, $J = 15.3$ Hz, 1 H), 3.95 (d, $J = 1.5$ Hz, 1 H), 2.95-2.80 (m, 1 H), 2.80-2.65 (m, 1 H), 1.92-1.50 (m, 8 H), 1.49-1.32 (m, 2 H), 1.32-1.00 (m, 5 H), 0.94 (t, $J = 7.2$ Hz, 3 H); ^{13}C NMR (75.4 MHz, CDCl_3) δ 162.6, 135.8, 135.3, 135.2, 128.7, 128.2, 127.6, 64.7, 45.6, 38.1, 34.9, 30.0, 29.2, 27.3, 26.5, 26.2, 26.1, 21.5, 13.7; MS (EI) m/z (%) 347 ($M^+({}^{37}\text{Cl})$, 0.74), 345 ($M^+({}^{35}\text{Cl})$, 1.84), 91 (100); IR (neat) 1748, 1713 cm^{-1} ; HRMS (MALDI/DHB) calcd for $\text{C}_{21}\text{H}_{29}{}^{35}\text{ClNO}$ (M^++1) 346.1932. Found 346.1970.

(4) (*E*)- α -(1-Chloro-3-phenylpropylidene)- β -(*i*-propyl)-*N*-benzyl- β -lactam ((*E*)-6k).

The reaction of **4f** (147 mg, 0.51 mmol), PdCl₂ (5 mg, 0.028 mmol), CuCl₂ (139 mg, 1.03 mmol), and benzoquinone (56 mg, 0.52 mmol) was stirred for 12 h at 45-50 °C to afford 125 mg (70 %) of (*E*)-**6k**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.40-7.10 (m, 10 H), 4.83 (d, *J* = 15.5 Hz, 1 H), 3.99 (d, *J* = 15.5 Hz, 1 H), 3.89 (d, *J* = 2.1 Hz, 1 H), 3.31-3.18 (m, 1 H), 3.11-2.88 (m, 3 H), 2.20-2.00 (m, 1 H), 0.82 (d, *J* = 7.5 Hz, 3 H), 0.77 (d, *J* = 7.2 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 162.3, 139.5, 136.4, 135.5, 133.7, 128.7, 128.6, 128.3, 128.1, 127.6, 126.1, 64.9, 45.5, 36.3, 33.2, 28.0, 19.1, 16.4; MS (EI) *m/z* (%) 355 (M⁺(³⁷Cl), 1.51), 353 (M⁺(³⁵Cl), 4.33), 91 (100); IR (neat) 1747, 1716 cm⁻¹; HRMS (MALDI/DHB) calcd for C₂₂H₂₅³⁵ClNO (M⁺+1) 354.1619. Found 354.1624.

(5) (*E*)- α -(1-Chloropentylidene)- β -methyl-*N*-benzyl- β -lactam ((*E*)-6l).

The reaction of **4h** (125 mg, 0.58 mmol), PdCl₂ (6 mg, 0.034 mmol), CuCl₂ (157 mg, 1.16 mmol), and benzoquinone (63 mg, 0.58 mmol) was stirred for 8 h at 30-40 °C to afford 98 mg (61 %) of **(E)-6l**: liquid; ¹H NMR (300 MHz, CDCl₃) δ 7.41-7.20 (m, 5 H), 4.70 (d, *J* = 15.3 Hz, 1 H), 4.18 (d, *J* = 15.3 Hz, 1 H), 4.03 (q, *J* = 6.1 Hz, 1 H), 2.75 (dt, *J* = 0.9 and 7.4 Hz, 2 H), 1.68-1.52 (m, 2 H), 1.48-1.22 (m, 2 H), 1.32 (d, *J* = 6.1 Hz, 3 H), 0.94 (t, *J* = 7.4 Hz, 3 H); ¹³C NMR (75.4 MHz, CDCl₃) δ 161.2, 138.1, 135.7, 134.9, 128.8, 128.1, 127.7, 55.5, 43.9, 34.8, 29.2, 21.5, 15.9, 13.7; MS (EI) *m/z* (%) 279 (M⁺(³⁷Cl), 4.46), 277 (M⁺(³⁵Cl), 13.41), 91 (100); IR (neat) 1748, 1716 cm⁻¹; HRMS calcd for C₁₆H₂₀³⁵ClNO (M⁺) 277.1233. Found 277.1253.

(6) (E)-α-(1-Chloropentylidene)-β-phenyl-N-Tosyl-β-lactam ((E)-6m):

The reaction of **4l** (167 mg, 0.49 mmol), PdCl₂ (5 mg, 0.028 mmol), CuCl₂ (137 mg, 1.01 mmol), and benzoquinone (59 mg, 0.55 mmol) was stirred for 12 h at 45-50 °C to afford 72 mg (36 %) of **(E)-6m**: solid, mp 103-104 °C (*n*-Hexane/Ethyl acetate); ¹H NMR (300 MHz, CDCl₃) δ 7.64-7.14 (m, 9 H), 5.49 (s, 1 H), 2.78 (t, *J* = 7.5 Hz, 2 H), 2.39 (s, 3 H), 1.75-1.48 (m, 2 H), 1.42-1.20 (m, 2 H), 0.90 (t, *J* = 7.2 Hz, 3 H); ¹³C

NMR (75.4 MHz, CDCl₃) δ 157.5, 145.7, 144.8, 136.0, 134.2, 133.4, 129.6, 129.2, 128.6, 128.0, 127.1, 65.2, 35.6, 29.2, 21.6, 21.5, 13.6; MS (EI) m/z (%) 405 (M⁺(³⁷Cl), 0.66), 403 (M⁺(³⁵Cl), 1.53), 91 (100); IR (KBr) 1775, 1701 cm⁻¹; Anal. Calcd for C₂₁H₂₂ClNO₃S: C, 62.44; H, 5.49; N, 3.47. Found: C, 62.37; H, 5.43; N, 3.54.

(7) (R)-(+)-(E)- α -(1-Chloro-3-phenylpropylidene)- β -(*i*-propyl)-*N*-benzyl- β -lactam ((R)-(+)-(E)-6k).

The reaction of **(R)-(+)-4f** (144 mg, 0.49 mmol, 98% ee), PdCl₂ (6 mg, 0.034 mmol), CuCl₂ (140 mg, 1.04 mmol), and benzoquinone (59 mg, 0.55 mmol), afforded 86 mg (50% yield) of **(R)-(+)-(E)-6k** with 98 % ee as determined by HPLC analysis (Chiralcel As-H, *n*-Hexane : *i*-PrOH = 100 : 0.5, 230 nm), t_r 11.2 (major), 12.4 (minor); $[\alpha]_D^{20} = +75.1$ ($c = 1.0$, CHCl₃).

(8) (R)-(+)-(E)- α -(1-Chloropentylidene)- β -methyl-*N*-benzyl- β -lactam ((R)-(+)-(E)-6l).

The reaction of **(R)-(+)-4h** (131 mg, 0.61 mmol, 97% ee), PdCl₂ (7 mg, 0.04 mmol), CuCl₂ (175 mg, 1.30 mmol), and benzoquinone (74 mg, 0.69 mmol), afforded 93 mg (55% yield) of **(R)-(+)-(E)-6l** with 94% ee as determined by HPLC analysis (Chiralcel AD-H, *n*-Hexane : *i*-PrOH = 90 : 10, 230 nm), *t_r* 6.4 (major), 7.0 (minor); [α]_D²⁰ = +51.7 (c = 1.1, CHCl₃).

(9) (S)-(-)-(E)-α-(1-Chloropentylidene)-β-methyl-N-benzyl-β-lactam ((S)-(-)-(E)-6l).

The reaction of **(S)-(-)-4h** (130 mg, 0.6 mmol, 95% ee), PdCl₂ (7 mg, 0.04 mmol), CuCl₂ (177 mg, 1.31 mmol), and benzoquinone (72 mg, 0.67 mmol), afforded 89 mg (53% yield) of **(S)-(-)-(E)-6l** with 93% ee as determined by HPLC analysis (Chiralcel AD-H, *n*-Hexane : *i*-PrOH = 90 : 10, 230 nm), *t_r* 8.1 (major), 9.1 (minor); [α]_D²⁰ = −53.1 (c = 0.97, CHCl₃).

(10) (*R*)-(+)-(*E*)- α -(1-Chloropentylidene)- β -ethyl-*N*-benzyl- β -lactam ((*R*)-(+)-(*E*)-6h**).**

The reaction of (*R*)-(+)-**4b** (134 mg, 0.59 mmol, 98% ee), PdCl₂ (6 mg, 0.034 mmol), CuCl₂ (178 mg, 1.32 mmol), and benzoquinone (75 mg, 0.69 mmol), afforded 84 mg (49 yield) of (*R*)-(+)-(*E*)-**6h** with 98% ee as determined by HPLC analysis (Chiralcel AD-H, *n*-Hexane : *i*-PrOH = 90 : 10, 230 nm), *t_r* 3.3 (major), 3.6 (minor); [α]_D²⁰ = +73.7 (c = 1.05, CHCl₃).

(11) (*S*)-(-)-(*E*)- α -(1-Chloropentylidene)- β -ethyl-*N*-benzyl- β -lactam ((*S*)-(-)-(*E*)-6h**):**

The reaction of (*S*)-(-)-**4b** (136 mg, 0.59 mmol, 96 % ee), PdCl₂ (6 mg, 0.034 mmol), CuCl₂ (184 mg, 1.36 mmol), and benzoquinone (72 mg, 0.67 mmol), afforded 98 mg (57 yield) of (*S*)-(-)-(*E*)-**6h** with 91% ee as determined by HPLC analysis (Chiralcel AD-H, *n*-Hexane : *i*-PrOH = 90 : 10, 230 nm), *t_r* 3.3 (minor), 3.6 (major); [α]_D²⁰ = -56.1 (c = 1.015, CHCl₃).

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wb-8-95-c

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wb-8-83-c

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wb-8-49-c

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wb-8-65-c

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