Stereoselectivity Control in the Rh(I)-Catalyzed Conjugate Additions of Aryl and Alkenylboronic Acids to Unprotected Hydroxycyclopentenones

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Supplementary material

General procedures and ^1H , ^{13}C -NMR and optical rotations of compounds **2-I** and **2-II**
(6 pages)

General Methods

All starting boronic acids were commercially available research-grade chemicals, and were used without further purification. $[\text{RhCl}(\text{COD})]_2$ was commercially available. Dioxane and MeOH were research-grade chemicals used without further purification. (*S*)-4-hydroxy-2-phenylcyclopentenone was prepared as previously reported.¹ Deionized water was used as co-solvent. Silica gel 60 F₂₅₄ was used for TLC, and the spots were detected with UV or vanillin solution. Flash column chromatography was carried out on silica gel 60. IR spectra have been recorded as CHCl_3 solutions. ^1H NMR spectra were recorded at 200 MHz or 300 MHz as indicated, in CDCl_3 solution. ^{13}C and ^{19}F NMR spectra were recorded at 50.5 MHz and 141.2 MHz respectively in CDCl_3 solution. MS spectra were carried out by EI at 70 eV. Optical rotations were determined at 25°C with a Na lamp in a Perkin-Elmer 241 apparatus using 1 mL cuvettes.

Reactions with $\text{R}^2\text{B}(\text{OH})_2$

General procedure.

$\text{R}^2\text{B}(\text{OH})_2$ (0.20 mol) and $[\text{RhCl}(\text{COD})]_2$ (0.005mol, 2.5 mg for Table 1, entries 1-17, 19-21 or 0.02 mol, 10 mg, entries 18, 21-24) were successively introduced in a flask and placed under Ar. A solution of **1a** (30 mg, 0.17 mol) in the corresponding solvent mixture was added (Table 1: conditions A, 0.5 mL, dioxane- H_2O 4:1; conditions B, 0.5 mL, MeOH- H_2O 6:1; conditions C, 0.6 mL, dioxane- H_2O 2:1). Last, Cs_2CO_3 , NaHCO_3 , LiOH, Et_3N , $\text{Mg}(\text{OH})_2$, $\text{Ba}(\text{OH})_2$, $\text{Zr}(\text{OH})_4$ or CsF were added (Eq given in Table 1). In the reactions with guanidine as base (Table 1, entries 15, 19-21), guanidinium hydrochloride (0.17 mmol, 16.4 mg) was added to the reaction mixture followed by LiOH (0.17 mmol, 7.2 mg). The reaction mixtures were stirred 16 h at rt. Evaporation under vacuum afforded the crude reaction products, which were purified by column chromatography (hexane-AcOEt, 20:80).

Characterization of compounds 2.

(-)-(2*R*, 3*R*, 4*S*)- 4-Hydroxy-2,3-diphenylcyclopentanone, 2a-I. $[\alpha]_D = -50$ (*c* 0.8, CHCl₃). ¹H NMR (300 MHz, CDCl₃) δ 7.31 - 7.02 (10H, m), 4.55 (1H, ddd, ³J = 7.6 Hz, ³J = 9.2 Hz, ³J = 9.7 Hz), 3.67 (1H, d, ³J = 13.0 Hz), 3.44 (1H, dd, ³J = 13.0 Hz, ³J = 9.2 Hz), 3.07 (1H, ddd, ²J = 18.6 Hz, ³J = 7.6 Hz, ³J = 1.2 Hz), 2.60 (1H, dd, ²J = 18.6, ³J = 9.7 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 211.4, 138.3, 135.6, 129.0, 128.6, 128.5, 127.6, 127.5, 127.3, 73.4, 62.4, 58.7, 46.6 Anal. Calcd for C₁₇H₁₆O₂: C, 80.93; H, 6.39. Found: C, 81.09; H, 6.47.

(-)-(2*R*, 3*R*, 4*S*)- 4-Hydroxy-3-(4-methoxyphenyl)-2-phenylcyclopentanone, 2b-I. $[\alpha]_D = -38$ (*c* 0.2, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.40 - 6.72 (9H, m), 4.44 (1H, ddd, ³J = 7.4 Hz, ³J = 9.7 Hz, ³J = 9.1 Hz), 3.70 (3H, s), 3.54 (1H, d, ³J = 13.2 Hz), 3.30 (1H, dd, ³J = 13.2 Hz, ³J = 9.1 Hz), 2.98 (1H, ddd, ²J = 18.0 Hz, ³J = 7.4 Hz, ³J = 1.0 Hz), 2.51 (1H, dd, ²J = 18.0, ³J = 9.7 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 212.3, 158.3, 136.1, 130.0, 129.0, 128.9, 127.7, 114.8, 73.9, 62.9, 58.3, 55.7, 47.0 Anal. Calcd for C₁₈H₁₈O₃: C, 76.57; H, 6.43. Found: C, 76.71; H, 6.52.

(-)(2*R*, 3*R*, 4*S*)- 4-Hydroxy-3-(3-methoxyphenyl)-2-phenylcyclopentanone, 2c-I. $[\alpha]_D = -43$ (*c* 1.0, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.30 - 6.62 (9H, m), 4.46 (1H, ddd, ³J = 7.5 Hz, ³J = 9.1 Hz, ³J = 9.8 Hz), 3.69 (3H, s), 3.57 (1H, d, ³J = 13.2 Hz), 3.33 (1H, dd, ³J = 13.2 Hz, ³J = 9.1 Hz), 2.98 (1H, ddd, ²J = 19.0 Hz, ³J = 7.5 Hz, ³J = 1.1 Hz), 2.51 (1H, dd, ²J = 19.0, ³J = 9.8 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 211.5, 160.1, 140.1, 135.8, 130.1, 128.7, 128.6, 127.4, 119.8, 113.9, 112.6, 73.5, 62.4, 58.7, 55.3, 46.7 Anal. Calcd for C₁₈H₁₈O₃: C, 76.57; H, 6.43. Found: C, 76.49; H, 6.34.

(2*R*, 3*R*, 4*S*)-4-Hydroxy-3-(2-methoxyphenyl)-2-phenylcyclopentanone, ()-2d-I. $[\alpha]_D = -50$ (*c* 1.4, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.20 - 6.75 (9H, m), 4.60 (1H, ddd, ³J = 7.6 Hz, ³J = 9.1 Hz, ³J = 10.1 Hz), 3.91 (1H, d, ³J = 13.3 Hz), 3.74 (3H, s), 3.73 (1H, dd, ³J = 13.3 Hz, ³J = 10.1 Hz), 2.97 (1H, ddd, ²J = 18.7 Hz, ³J = 7.6 Hz, ³J = 1.1 Hz), 2.49 (1H, dd, ²J = 18.7, ³J = 9.1 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 212.5,

¹ Csáky, A. G.; Mba, M.; Plumet, J. *Tetrahedron Asymm.* **2004**, *15*, 647

157.9, 136.3, 128.9, 128.6, 128.5, 127.1, 126.6, 121.3, 111.3, 72.6, 60.5, 55.5, 53.9, 47.2. Anal. Calcd for $C_{18}H_{18}O_3$: C, 76.57; H, 6.43. Found: C, 76.44; H, 6.28.

(-)-(2*R*, 3*R*, 4*S*)- 4-Hydroxy-2-phenyl-3-(4-trifluoromethylphenyl)cyclopentanone, 2e-I. $[\alpha]_D = -29$ (*c* 1.5, $CHCl_3$). 1H NMR (200 MHz, $CDCl_3$) δ 7.55 - 6.98 (9H, m), 4.49 (1H, ddd, $^3J = 7.5$ Hz, $^3J = 8.7$ Hz, $^3J = 9.5$ Hz), 3.58 (1H, d, $^3J = 13.3$ Hz), 3.44 (1H, dd, $^3J = 13.3$ Hz, $^3J = 8.7$ Hz), 3.00 (1H, ddd, $^2J = 18.6$ Hz, $^3J = 7.5$ Hz, $^3J = 1.0$ Hz), 2.53 (1H, dd, $^2J = 18.6$, $^3J = 9.5$ Hz). ^{13}C NMR (50.5 MHz, $CDCl_3$) δ 210.6, 142.6, 135.1, 128.7, 128.4, 128.0, 127.5, 125.9, 125.8, 125.7, 125.6, 73.0, 62.3, 58.1, 46.7. Anal. Calcd for $C_{18}H_{15}F_3O_2$: C, 67.50; H, 4.72. Found: C, 67.61; H, 4.54.

(-)-*E*-(2*R*, 3*S*, 4*S*)- 4-Hydroxy-2-phenyl-3-styrylcyclopentanone, 2f-I. $[\alpha]_D = -58$ (*c* 0.3, $CHCl_3$). 1H NMR (200 MHz, $CDCl_3$) δ 7.33 - 7.01 (10H, m), 6.44 (1H, d, $^3J = 15.8$ Hz), 6.10 (1H, dd, $^3J = 15.8$ Hz, $^3J = 8.2$ Hz), 4.28 (1H, m), 3.29 (1H, d, $^3J = 12.7$ Hz), 2.96 (2H, m), 2.44 (1H, dd, $^2J = 18.6$ Hz, $^3J = 9.7$ Hz). ^{13}C NMR (50.5 MHz, $CDCl_3$) δ 211.3, 136.3, 135.5, 133.9, 128.9, 128.6, 128.5, 127.7, 127.5, 127.2, 126.2, 71.7, 61.5, 56.5, 46.2. Anal. Calcd for $C_{19}H_{18}O_2$: C, 81.99; H, 6.52. Found: C, 81.89; H, 6.44.

(+)-*E*-(2*S*, 3*R*, 4*S*)- 4-Hydroxy-2-phenyl-3-styrylcyclopentanone, 2f-II. $[\alpha]_D = +134$ (*c* 0.8, $CHCl_3$). 1H NMR (200 MHz, $CDCl_3$) δ 7.35 - 7.01 (10H, m), 6.44 (1H, d, $^3J = 16.2$ Hz), 6.33 (1H, dd, $^3J = 16.2$ Hz, $^3J = 6.6$ Hz), 4.57 (1H, m), 3.70 (1H, d, $^3J = 14.5$ Hz), 3.17 (1H, m), 2.63 (2H, m). ^{13}C NMR (50.5 MHz, $CDCl_3$) δ 214.8, 136.7, 136.6, 134.17, 128.8, 128.7, 127.9, 127.3, 126.4, 126.1, 70.3, 55.9, 53.0, 47.5. Anal. Calcd for $C_{19}H_{18}O_2$: C, 81.99; H, 6.52. Found: C, 82.21; H, 6.47.

(-)-*E*-(2*R*, 3*S*, 4*S*)- 4-Hydroxy-2-phenyl-3-[2-(*p*-tolyl)vinyl]cyclopentanone, 2g-I. $[\alpha]_D = -69$ (*c* 0.7, $CHCl_3$). 1H NMR (200 MHz, $CDCl_3$) δ 7.35 - 6.95 (9H, m), 6.41 (1H, d, $^3J = 15.9$ Hz), 6.04 (1H, dd, $^3J = 15.9$, $^3J = 8.2$), 4.27 (1H, m), 3.28 (1H, d, $^3J = 12.7$ Hz), 2.94 (2H, m), 2.43 (1H, dd, $^2J = 18.6$ Hz, $^3J = 9.7$ Hz), 2.29 (3H, s). ^{13}C NMR (50.5 MHz, $CDCl_3$) δ 211.5, 137.7, 135.7, 133.9, 133.6, 129.3, 128.7, 128.6, 127.3, 126.5, 126.2, 71.8, 61.7, 56.7, 46.3, 21.2. Anal. Calcd for $C_{20}H_{20}O_2$: C, 82.16; H, 6.89. Found: C, 82.25; H, 7.05.

(+)-*E*-(2*S*, 3*R*, 4*S*)- 4-Hydroxy-2-phenyl-3-[2-(*p*-tolyl)vinyl]cyclopentanone, 2g-II. $[\alpha]_D = +93$ (*c* 1.5, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.40 - 6.98 (9H, m), 6.41 (1H, d, ³*J* = 16.2 Hz), 6.27 (1H, dd, ³*J* = 16.2, ³*J* = 6.8), 4.57 (1H, m), 3.69 (1H, d, ³*J* = 12.5 Hz), 3.17 (1H, m), 2.58 (2H, m), 2.25 (3H, s). ¹³C NMR (50.5 MHz, CDCl₃) δ 214.8, 137.7, 136.6, 133.9, 133.7, 129.3, 128.6, 127.1, 126.2, 124.8, 70.2, 55.8, 52.9, 47.4, 21.2. Anal. Calcd for C₂₀H₂₀O₂: C, 82.16; H, 6.89. Found: C, 82.31; H, 6.74.

(-)-*E*-(2*R*, 3*S*, 4*S*)- 3-[2-(*p*-Chlorophenyl)vinyl]-4-hydroxy-2-phenylcyclopentanone, 2h-I. $[\alpha]_D = -91$ (*c* 1.1, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.27 - 7.05 (9H, m), 6.38 (1H, d, ³*J* = 15.8 Hz), 6.08 (1H, dd, ³*J* = 15.8, ³*J* = 8.0), 4.56 (1H, m), 3.28 (1H, d, ³*J* = 12.7 Hz), 2.94 (2H, m), 2.43 (1H, ²*J* = 18.6 Hz, ³*J* = 9.7 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 211.2, 135.6, 134.9, 133.5, 132.7, 128.8, 128.6, 128.4, 127.5, 127.4, 71.8, 61.4, 56.5, 46.4. Anal. Calcd for C₁₉H₁₇ClO₂: C, 72.96; H, 5.48. Found: C, 72.78; H, 5.39.

(+)-*E*-(2*S*, 3*R*, 4*S*)- 3-[2-(*p*-Chlorophenyl)vinyl]-4-hydroxy-2-phenylcyclopentanone, 2h-II. $[\alpha]_D = +123$ (*c* 1.4, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.49 - 6.95 (9H, m), 6.37 (1H, d, ³*J* = 16.0 Hz), 6.32 (1H, dd, ³*J* = 16.2, ³*J* = 6.0), 4.57 (1H, m), 3.67 (1H, d, ³*J* = 12.5 Hz), 3.16 (1H, m), 2.59 (2H, m). ¹³C NMR (50.5 MHz, CDCl₃) δ 214.2, 136.4, 134.9, 133.3, 132.6, 128.6, 128.5, 127.8, 127.4, 127.1, 126.7, 70.1, 55.8, 52.8, 47.5. Anal. Calcd for C₁₉H₁₇ClO₂: C, 72.96; H, 5.48. Found: C, 73.11; H, 5.55.

(-)-*E*-(2*R*, 3*S*, 4*S*)- 4-Hydroxy-2-phenyl-3-[2-(*p*-trifluorophenyl)vinyl]cyclopentanone, 2i-I. $[\alpha]_D = -38$ (*c* 0.4, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.49 - 7.06 (9H, m), 6.46 (1H, d, ³*J* = 15.9 Hz), 6.23 (1H, dd, ³*J* = 7.8 Hz, ³*J* = 15.9 Hz), 4.33 (1H, m), 3.31 (1H, d, ³*J* = 13.0 Hz), 2.99 (2H, m), 2.46 (1H, dd, ²*J* = 18.6 Hz, ³*J* = 9.7 Hz). ¹³C NMR (50.5 MHz, CDCl₃) δ 210.9, 138.6, 135.5, 132.6, 130.5, 128.8, 128.6, 127.5, 126.5, 125.6, 125.5, 71.7, 61.6, 56.4, 46.1. Anal. Calcd for C₂₀H₁₇F₃O₂: C, 69.36; H, 4.95. Found: C, 69.25; H, 4.79.

(+)-*E*-(2*S*, 3*R*, 4*S*)- 4-Hydroxy-2-phenyl-3-[2-(*p*-trifluorophenyl)vinyl]cyclopentanone, 2i-II. $[\alpha]_D = +114$ (*c* 1.2, CHCl₃). ¹H NMR (200 MHz, CDCl₃) δ 7.48 - 7.03 (9H, m), 6.43 (2H, m), 4.60 (1H, m), 3.69 (1H, d, ³*J* = 12.4 Hz), 3.19 (1H, m), 2.59

(2H, m). ^{13}C NMR (50.5 MHz, CDCl_3) δ 214.5, 139.9, 136.4, 132.3, 129.1, 128.6, 128.5, 127.1, 126.3, 125.4, 125.3, 70.0, 55.9, 53.0, 47.6. Anal. Calcd for $\text{C}_{20}\text{H}_{17}\text{F}_3\text{O}_2$: C, 69.36; H, 4.95. Found: C, 69.44; H, 5.12.