Chemo- and Diastereoselective Tandem Dual Oxidation of B(pin)-substituted Allylic Alcohols: Synthesis of B(pin)-substituted Epoxy Alcohols, 2-Keto-*anti*-1,3-diols and Dihydroxy-tetrahydrofuran-3-ones

Nusrah Hussain, Mahmud M. Hussain, Patrick J. Carroll and Patrick J. Walsh*

P. Roy and Diana T. Vagelos Laboratories, Department of Chemistry, University of Pennsylvania, 231 S. 34th Street, Philadelphia, PA 19104-6323
pwalsh@sas.upenn.edu

Supporting Information

Part 1

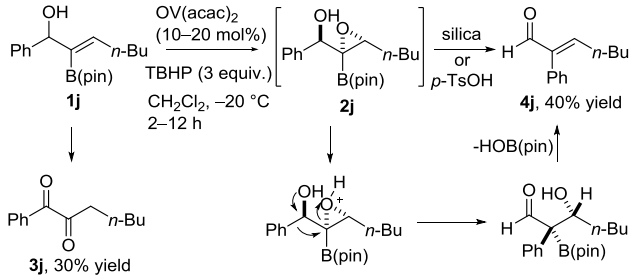
Table of Contents Page **Page**

General Methods. All reactions were performed under a nitrogen atmosphere with oven-dried glassware. All manipulations involving dicyclohexylborane and dimethylzinc were carried out under an inert atmosphere in a Vacuum Atmospheres drybox with an attached MO-40 Dritrain or by using standard Schlenk or vacuum line techniques. Chemicals were obtained from Aldrich, Acros, or Strem Chemicals unless otherwise specified. The oxidant *tert*-butylhydroperoxide (TBHP) was purchased from Aldrich as a ~5.5 M anhydrous solution in decane and hydrogen peroxide from Fischer as a 30% aqueous solution. Solvents were purchased from Fischer Scientific. Toluene and dichloromethane were dried through activated alumina columns. Tetrahydrofuran was distilled from sodium and benzophenone under N_2. Liquid substrates were distilled prior to use. B(pin)-substituted alkynes were prepared by literature methods.[1-9] Neat dimethylzinc was obtained from Akzo Nobel from which 2.0 M solutions in toluene were prepared and stored in a Vacuum Atmospheres drybox. NMR spectra were obtained on Brüker 300, 360, 400 or 500 MHz Fourier transform spectrometers at the University of Pennsylvania NMR facility. ^{1}H and $^{13}C\{^{1}H\}$ NMR spectra were referenced to residual solvent. $^{11}B\{^{1}H\}$ NMR spectra were referenced to $BF_3 \cdot OEt_2$. The infrared spectra were obtained using a Perkin-Elmer 1600 series spectrometer. HRMS data was obtained on a Waters LC-TOF mass spectrometer (model LCT-XE Premier) using electrospray ionization in positive or negative mode, depending on analyte. Melting points were determined on a Uni-melt Thomas Hoover melting point apparatus and are uncorrected. Thin-layer chromatography was performed on Whatman precoated silica gel 60 F-254 plates and visualized by ultraviolet light or by staining with ceric ammonium molybdate, phosphomolybdic acid or potassium permanganate solutions. Silica gel (Silicaflash, P60, 40-63 μm, Silicycle) was used for airflashed chromatography, and deactivated silica gel was prepared by addition of 15 mL of Et_3N to 1 L of silica gel. Full characterizations

of compounds **1a**–**1j**, **2b**–**2h**, **2j**, **3j**, **4j** and **5a**–**5i** were reported in our preliminary communication.[8]

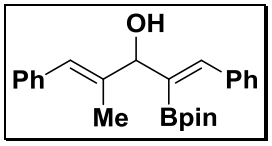
Caution. *Dialkylzinc reagents are pyrophoric. Care must be used when handling them.*

Optimization of the epoxidation of the benzylic substrate **1j** proved to be more challenging. The epoxide **2j** was observed by TLC along with the diketone **3j** (Scheme S1). Purification of the reaction mixture on silica gel resulted in decomposition of the B(pin)-substituted epoxide with formation of the α,β-unsaturated aldehyde **4j** in ~40% yield (entries 12–13 in Table S2, and Scheme S1). We hypothesized that the enal **4j** arose via an acid or Lewis acid promoted semi-pinacol rearrangement followed by *syn*-elimination of the HO–B(pin). A similar HO–BAr_2 elimination takes place in the boron Wittig-type reaction.[10, 11] The elimination mechanism in Scheme S1 is consistent with the observed double bond geometry in the enal **4j**. The byproduct **3j** was identified as the known diketone.[12] Vanadium(V) catalysts are known to oxidize alcohols to the corresponding ketones in the presence of TBHP.[13, 14] Diketone **3j** may be formed by initial oxidation of the benzylic alcohol to the ketone followed by oxidation of the vinyl boronate ester to form the dione.



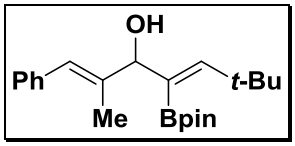
Scheme S1. Key Intermediates in the Proposed Mechanism of the Epoxy Alcohol Rearrangement to form Enal **4j**

General Procedure A: Synthesis of B(pin)-substituted Bis-allylic Alcohols. To a suspension of $HBCy_2$ (1.2 equiv.) in toluene (2.0 mL) under N_2 was added alkyne-4,4,5,5-tetramethyl-[1,3,2]-dioxaborolane (1.2 equiv.) and the reaction mixture was stirred for 30 min at rt, after which it was homogeneous. The reaction vessel was cooled to –78 °C and treated with Me_2Zn (1.2 equiv., 2.0 M in toluene) for 30–45 min. The solution was then warmed to –10 °C and the enal (1 equiv.) was added. The reaction mixture was stirred at –15 °C until TLC showed complete consumption of the aldehyde (8–12 h). The reaction mixture was then diluted with EtOAc and quenched with saturated NH_4Cl at 0 °C. The organic layer was separated and the aqueous solution was extracted three times with 10 mL of EtOAc. The combined organic solution was dried over Na_2SO_4, filtered and the solvent was removed under reduced pressure. The crude product was purified by flash column chromatography on silica gel. The bis-allylic alcohol products are susceptible to oxidation of the B–C bond on silica under air. Rapid purification is therefore necessary to minimize oxidation to the ketones, which elute at similar R_f values to the bis-allylic alcohols. The bis-allylic alcohols are stored under N_2 at 0 °C to preserve their purity.

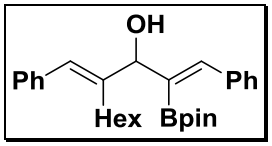


(1*E*,4*E*)-2-Methyl-1,5-diphenyl-4(4,4,5,5-tetramethyl-1,3,2-dioxaborolane-2-yl)penta-1,4-dien-3-ol (1k). The product was prepared by General Procedure A using *α*-methyl cinnamaldehyde (0.42 mL, 3.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.82 g, 3.6 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1k** (1.04 g, 92% yield). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44 (d, *J* = 7.1 Hz, 2H), 7.38 –

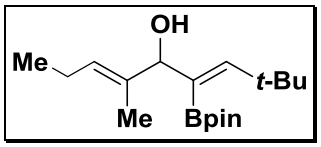
7.20 (m, 8H), 7.18 (s, 1H), 6.71 (s, 1H), 4.86 (d, *J* = 4.5 Hz, 1H), 2.65 (d, *J* = 5.7 Hz, 1H), 1.90 (s, 3H), 1.24 (s, 12H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 141.0, 139.2, 137.9, 137.7, 129.0, 128.3, 128.0, 127.9, 127.6, 126.2, 125.2, 83.9, 81.9, 24.9, 24.7, 14.8 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 30.5; IR (neat) 3448, 3058, 3026, 2930, 2855, 1684, 1625, 1600, 1494, 1449, 1312, 1248, 1143 cm^{-1}; HRMS *m/z* 399.2118 [$(M+Na)^+$; calcd for $C_{24}H_{29}BO_3Na$: 399.2107].



(1*E*,4*E*)-2,6,6-Trimethyl-1-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hepta-1,4-dien-3-ol (1l). The product was prepared by General Procedure A using *α*-methyl cinnamaldehyde (0.28 mL, 2.0 mmol) and 2-(3,3-dimethylbut-1-ynl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1l** (0.60 g, 84% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.38 – 7.27 (m, 4H), 7.23 – 7.17 (m, 1H), 6.66 (s, 1H), 6.14 (s, 1H), 4.54 (d, *J* = 5.4 Hz, 1H), 2.55 (d, *J* = 6.3 Hz, 1H), 1.79 (s, 3H), 1.25 (s, 6H), 1.24 (s, 6H), 1.14 (s, 9H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 154.1, 139.9, 138.3, 129.3, 128.2, 126.3, 124.1, 84.0, 83.4, 34.3, 30.5, 25.4, 25.3, 15.5 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 30.0; IR (neat) 3469, 3023, 2978, 2954, 1640, 1600, 1480, 1380, 1304, 1253, 1142 cm^{-1}; HRMS *m/z* 379.2425 [$(M+Na)^+$; calcd for $C_{22}H_{33}BO_3Na$: 379.2420].

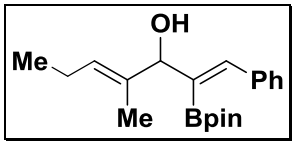


(1*E*,4*E*)-4-Benzylidene-1-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)dec-1-en-3-ol (1m). The product was prepared by General Procedure A using *α*-hexyl cinnamaldehyde (0.46 mL, 2.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1m** (0.54 g, 60% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 – 7.39 (m, 2H), 7.33 – 7.26 (m, 7H), 7.23 – 7.20 (m, 1H), 7.18 (s, 1H), 6.69 (s, 1H), 4.91 (s, 1H), 2.74 (s, 1H), 2.53 – 2.38 (m, 1H), 2.24 – 2.14 (m, 1H), 1.54 (p, *J* = 7.3 Hz, 2H), 1.31 – 1.21 (m, 18H), 0.86 (t, *J* = 6.7 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 144.4, 141.8, 138.2, 138.1, 128.9, 128.7, 128.2, 128.1, 127.9, 126.5, 125.4, 84.1, 80.5, 31.7, 29.7, 29.0, 28.8, 25.2, 24.9, 22.8, 14.3 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.3; IR (neat) 3423, 3057, 3025, 2928, 2856, 1685, 1625, 1600, 1493, 1450, 1379, 1310, 1249, 1142 cm^{-1}; HRMS *m/z* 469.2896 [$(M+Na)^+$; calcd for $C_{29}H_{39}BO_3Na$: 469.2890].

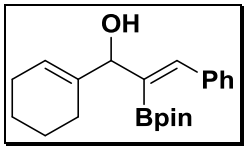


(3*E*,6*E*)-2,2,6-Trimethyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)nona-3,6-dien-5-ol (1n). The product was prepared by General Procedure A using (*E*)-2-methylpent-2-enal (0.23 mL, 2.0 mmol) and 2-(3,3-dimethylbut-1-ynl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1n** (0.41 g, 67% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.00 (s, 1H), 5.51 – 5.40 (m, 1H), 4.37 (s, 1H), 2.33 (s, 1H), 2.01 (p, *J* = 7.6 Hz, 2H), 1.49 (s, 3H), 1.23 (s, 6H), 1.22 (s, 6H), 1.07 (s, 9H), 0.95

(t, *J* = 7.6 Hz, 3H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 152.5, 136.0, 126.6, 83.7, 82.5, 82.4, 34.0, 30.5, 25.2, 21.1, 14.2, 13.0 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 37.0; IR (neat) 3479, 2958, 2872, 1640, 1480, 1463, 1380, 1301, 1253, 1144 cm^{-1}; HRMS *m/z* 331.2419 $[(M+Na)^+$; calcd for $C_{18}H_{33}BO_3Na$: 331.2420].

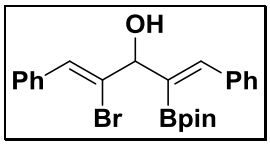


(1*E*,4*E*)-4-Methyl-1-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hepta-1,4-dien-3-ol (1o). The product was prepared by General Procedure A using (*E*)-2-methylpent-2-enal (0.23 mL, 2.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1o** (0.37 g, 56% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 (d, *J* = 7.7 Hz, 2H), 7.33 – 7.17 (m, 3H), 7.09 (s, 1H), 5.56 (t, *J* = 6.9 Hz, 1H), 4.71 (s, 1H), 2.42 (s, 1H), 2.08 (p, *J* = 7.2 Hz, 2H), 1.64 (s, 3H), 1.24 (s, 12H), 1.00 (t, *J* = 7.5 Hz, 3H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 140.1, 138.3, 135.8, 128.5, 128.12 128.1, 127.6, 84.0, 81.4, 25.0, 24.9, 21.2, 14.2, 12.8 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 30.0; IR (neat) 3433, 3027, 2930, 2977, 2873, 1629, 1600, 1494, 1449, 1380, 1310, 1247, 1143 cm^{-1}; HRMS *m/z* 351.2119 $[(M+Na)^+$; calcd for $C_{20}H_{29}BO_3Na$: 351.2107].



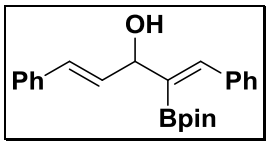
(*E*)-1-Cyclohexenyl-3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-2-en-1-ol (1p). The product was prepared by General Procedure A using cyclohex-1-

enecarbaldehyde (0.23 mL, 2.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1p** (0.48 g, 71% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 (d, *J* = 7.2 Hz, 2H), 7.28 (t, *J* = 7.1 Hz, 2H), 7.23 (t, *J* = 7.2 Hz, 1H), 7.08 (s, 1H), 5.84 – 5.78 (m, 1H), 4.65 (s, 1H), 2.47 (s, 1H), 2.10 – 1.96 (m, 4H), 1.69 – 1.52 (m, 4H), 1.25 (s, 12H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 140.3, 139.3, 138.2, 128.5, 128.1, 127.6, 122.8, 84.0, 80.7, 25.2, 25.1, 25.0, 24.9, 22.8, 22.7 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.3; IR (neat) 3423, 3026, 2978, 2927, 2856, 1626, 1600, 1495, 1449, 1389, 1309, 1248, 1142 cm^{-1}; HRMS *m/z* 363.2103 [$(M+Na)^+$; calcd for $C_{21}H_{29}BO_3Na$: 363.2107].



(1*Z*,4*E*)-2-Bromo-1,5-diphenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)penta-1,4-dien-3-ol (1q). The product was prepared by General Procedure A using α-bromo cinnamaldehyde (0.42 mL, 2.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.55 g, 2.4 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1q** (0.81 g, 92% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (d, *J* = 7.7 Hz, 2H), 7.43 (d, *J* = 7.6 Hz, 2H), 7.39 – 7.18 (m, 8H), 5.03 (d, *J* = 7.0 Hz, 1H), 3.19 (d, *J* = 8.1 Hz, 1H), 1.22 (s, 12H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 144.1, 137.6, 135.5, 129.3, 128.9, 128.8, 128.3, 128.2, 128.2, 128.1, 128.1, 84.3, 82.2, 25.1, 24.9 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.2; IR (neat) 3433, 3025, 2979, 2930, 2874,

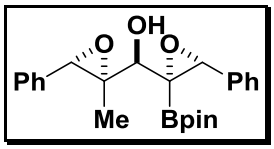
1627, 1600, 1493, 1447, 1391, 1313, 1249, 1141 cm^{-1}; HRMS *m/z* 463.1042 $[(M+Na)^+$; calcd for $C_{23}H_{26}BBrO_3Na$: 463.1056].



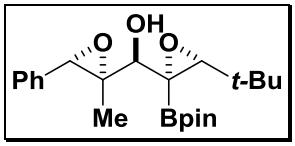
(1*E*,4*E*)-1,5-Diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)penta-1,4-dien-3-ol (1r). The product was prepared by General Procedure A using cinnamaldehyde (0.13 mL, 1.0 mmol) and 4,4,5,5-tetramethyl-2-(phenylethynyl)-1,3,2-dioxaborolane (0.27 g, 1.2 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the bis-allylic alcohol **1r** (0.33 g, 92% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 – 7.36 (m, 4H), 7.36 – 7.22 (m, 6H), 7.17 (s, 1H), 6.66 (d, J = 16 Hz, 1H), 6.39 (dd, *J* = 16.8, 5.8 Hz, 1H), 4.99 (s, 1H), 2.67 (s, 1H), 1.25 (s, 6H), 1.25 (s, 6H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 141.7, 137.9, 137.0, 131.7, 130.5, 128.7, 128.7, 128.1, 128.0, 127.7, 126.7, 84.2, 78.5, 35.7, 25.1, 24.8 (the quaternary vinyl C bearing the boron is not observed).

General Procedure B: Synthesis of B(pin)-substituted Bis-epoxides. To a Schlenk flask containing the B(pin)-substituted bis-allylic alcohol (1.0 equiv.) was added 1 mL of freshly distilled CH_2Cl_2 followed by solid $OV(acac)_2$ (10 mol %) under N_2. The resulting greenish-blue solution was cooled to 0 ºC and a solution of TBHP (0.7–3.0 equiv., ~5.5 M solution in decane) in 1 mL of CH_2Cl_2 was added slowly to the reaction mixture over 10 min using a syringe pump at that temperature. The solution rapidly changed color to a dark brown. The reaction mixture was stirred at 0 ºC until TLC showed complete consumption of the bis-allylic alcohol (30 min –2 h). The crude reaction mixture was filtered through a short pad of silica, and the solvent was

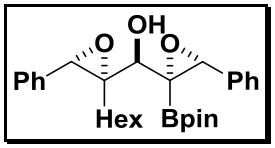
removed under reduced pressure (>90% purity by ^{1}H NMR). The crude product was further purified by flash column chromatography on silica gel. The epoxy boronate ester is susceptible to oxidation of the B–C bond on silica under air, and hence a rapid purification is necessary to minimize oxidation to the corresponding diol and other side products.



(2-Methyl-3-phenyloxiran-2-yl)(3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methanol (2k). The product was prepared by General Procedure B using bis-allylic alcohol **1k** (0.07 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (38.2 μL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the epoxide (>90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2k** (19.7 mg, 69% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.39 (m, 2H), 7.32 – 7.27 (m, 2H), 7.26 – 7.22 (m, 1H), 4.02 (s, 1H), 3.50 (d, *J* = 3.1 Hz, 1H), 3.38 (s, 1H), 2.72 (s, 1H), 2.14 – 2.06 (m, 1H), 1.97 – 1.82 (m, 3H), 1.51 – 1.39 (m, 2H), 1.35 – 1.25 (m, 2H), 1.00 (s, 6H), 0.93 (s, 6H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 136.0, 135.7. 128.2, 128.1, 128.0, 127.7, 126.9, 126.5, 84.8, 80.1, 65.2, 61.2, 60.1, 24.9, 24.6, 13.9 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 29.7; IR (neat) 3521, 3032, 2979, 2931, 1605, 1498, 1454, 1381, 1335, 1250, 1134 cm^{-1}; HRMS *m/z* 431.1975 [$(M+Na)^+$; calcd for $C_{20}H_{29}BO_4Na$: 431.2007].

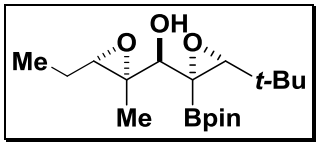


(3-*tert*-Butyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)(2-methyl-3-phenyloxiran-2-yl)methanol (2l). The product was prepared by General Procedure B using bis-allylic alcohol **1l** (0.10 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (54.5 μL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the bis-epoxide (>90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2k** (28.0 mg, 72% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 – 7.17 (m, 5H), 4.41 (s, 1H), 3.35 (s, 1H), 2.84 (s, 2H), 1.37 (s, 6H), 1.35 (s, 6H), 1.15 (s, 3H), 1.03 (s, 9H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 135.8, 128.1, 127.6, 126.8, 85.0, 80.8, 71.5, 65.1, 61.4, 31.7, 27.0, 25.8, 25.5, 13.9 (the quaternary vinyl C bearing the boron is not observed).



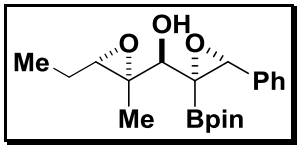
(2-Hexyl-3-phenyloxiran-2-yl)(3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)oxiran-2-yl)methanol (2m). The product was prepared by General Procedure B using bis-allylic alcohol **1m** (0.890 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.49 mL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the bis-epoxide (0.37 g, 86% ^{1}H NMR yield with internal standard CH_2Br_2, >90% purity by ^{1}H NMR). The product was further purified by

flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2m** (0.34 g, 80% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 (d, *J* = 7.4 Hz, 2H), 7.36 – 7.26 (m, 8H), 4.48 (s, 1H), 4.10 (s, 1H), 3.66 (d, *J* = 10.7 Hz, 1H), 2.96 (d, *J* = 10.8 Hz, 1H), 2.02 (ddd, *J* = 13.2, 10.4, 4.8 Hz, 1H), 1.21 – 1.14 (m, 1H), 1.13 – 1.07 (m, 2H), 1.06 – 0.97 (m, 10H), 0.96 (s, 6H), 0.76 (t, *J* = 7.2 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 136.0, 135.7, 128.1, 128.0, 128.0, 127.7, 126.9, 126.6, 84.8, 77.8, 68.0, 61.1, 61.0, 31.4, 29.3, 26.9, 24.8, 24.6, 22.5, 14.2 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 28.4; IR (neat) 3521, 3032, 2979, 2931, 1605, 1498, 1454, 1418, 1381, 1335, 1250, 1134 cm^{-1}; HRMS *m/z* 431.1975 [$(M+Na)^{+}$; calcd for $C_{24}H_{29}BO_5Na$: 431.2006].

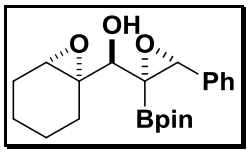


(3-(*tert*-Butyl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)oxiran-2-yl)(3-ethyl-2-methyloxiran-2-yl)methanol (2n). The product was prepared by General Procedure B using bis-allylic alcohol **1n** (0.89 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.49 mL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the bis-epoxide (0.27 g, 88% ^{1}H NMR yield with internal standard CH_2Br_2, >90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2n** (0.24 g, 80% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.24 (dd, *J* = 7.5, 5.1 Hz, 1H), 3.14 (s, 1H), 2.74 (s, 1H), 2.69 (s, 1H), 1.65 – 1.47 (m, 2H), 1.35 (s, 3H), 1.33 (s, 12H), 1.04 (t, *J* = 7.5 Hz, 3H), 0.99 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 84.8, 81.4,

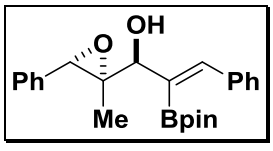
72.0, 63.0, 62.3, 31.6, 27.0, 25.9, 25.5, 21.8, 14.3, 10.8 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^1H\}$ NMR ($CDCl_3$,128 MHz) δ 30.0; IR (neat) 3525, 2977, 2933, 1411, 1381, 1334, 1250, 1135 cm^{-1}.



(3-Ethyl-2-methyl-2-methyloxiran-2-yl)(3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)methanol (2o). The product was prepared by General Procedure B using bis-allylic alcohol **1o** (0.19 g, 0.59 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.32 mL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the bis-epoxide (0.19 g, 90% ^1H NMR yield with internal standard CH_2Br_2, >90% purity by ^1H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2o** (0.18 g, 84% yield). ^1H NMR (500 MHz, $CDCl_3$) δ 7.46 – 7.39 (m, 2H), 7.33 – 7.25 (m, 3H), 4.02 (s, 1H), 3.35 (d, *J* = 10.1 Hz, 1H), 3.29 (dd, *J* = 7.2, 5.4 Hz, 1H), 2.78 (d, *J* = 10.3 Hz, 1H), 1.70 – 1.52 (m, 2H), 1.44 (s, 3H), 1.08 (t, *J* = 7.5 Hz, 3H), 1.01 (s, 6H), 0.93 (s, 6H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 136.0, 128.1, 128.0, 126.6, 84.7, 80.4, 63.1, 62.2, 61.1, 24.9, 24.5, 21.8, 14.2, 10.7 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^1H\}$ NMR ($CDCl_3$,128 MHz) δ 29.4; IR (neat) 3525, 2976, 2932, 1600, 1455, 1421, 1381, 1335, 1250, 1135 cm^{-1}; HRMS *m/z* 383.2007 [$(M+Na)^+$; calcd for $C_{20}H_{29}BO_5Na$: 383.2006].

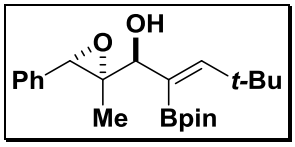


(7-Oxabicycloheptan-1-yl)(3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)oxiran-2-yl)methanol (2p). The product was prepared by General Procedure B using bis-allylic alcohol **1p** (0.12 g, 0.34 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.19 mL, ~5.5 M solution in decane, 3 equiv.). The TBHP solution was added slowly to the reaction mixture over 10 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the bis-epoxide (0.10 g, 82% ^{1}H NMR yield with internal standard CH_2Br_2, >90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford a single diastereomer of the bis-epoxide **2p** as white solid (92.4 mg, 73% yield). M.p 104-107 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.39 (m, 2H), 7.32 – 7.27 (m, 2H), 7.26 – 7.22 (m, 1H), 4.02 (s, 1H), 3.50 (d, *J* = 3.1 Hz, 1H), 3.38 (s, 1H), 2.72 (s, 1H), 2.14 – 2.06 (m, 1H), 1.97 – 1.82 (m, 3H), 1.51 – 1.39 (m, 2H), 1.35 – 1.25 (m, 2H), 1.00 (s, 6H), 0.93 (s, 6H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 136.0, 128.1, 128.0, 126.5, 84.6, 80.1, 61.9, 60.9, 56.5, 25.6, 24.9, 24.6, 24.5, 20.1, 19.7 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 29.7; IR (neat) 3529, 3062, 2978, 2936, 2860, 1605, 1498, 1450, 1421, 1381, 1336, 1249, 1132 cm^{-1}; HRMS *m/z* 395.2014 [(M+Na)$^+$; calcd for $C_{21}H_{29}BO_5Na$: 395.2006].



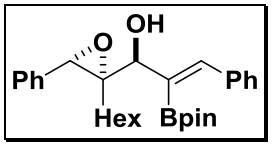
(*E*)-1-(2-Methyl-3-phenyloxiran-2-yl)-3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-2-en-1-ol (3k). The product was prepared by General Procedure B using bis-allylic alcohol **1k** (0.10 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2

(18.2 μL, ~5.5 M solution in decane, 1 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3k** (27.1 mg, 69% yield). ^{1}H NMR (500 MHz, $CDCl_3$); δ 7.47 – 7.25 (m, 10H), 7.14 (s, 1H), 4.51 (s, 1H), 4.41 (s, 1H), 2.81 (s, 1H), 1.35 (s, 6H), 1.31 (s, 6H), 1.15 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 142.8, 138.0, 136.4, 128.7, 128.2, 128.2, 128.1, 127.5, 126.7, 84.2, 80.1, 65.7, 60.5, 25.2, 25.1, 14.3 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.2; IR (neat) 3445, 3028, 2978, 2929, 2856, 1626, 1601, 1497, 1449, 1391, 1380, 1311, 1252, 1143 cm^{-1}.

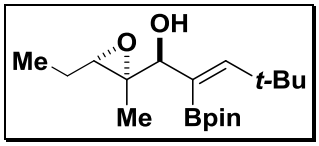


(*E*)-4,4-Dimethyl-1-(2-methyl-3-phenyloxiran-2-yl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pent-2-en-1-ol (3l). The product was prepared by General Procedure B using bis-allylic alcohol **1l** (0.1 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (14.6 μL, ~5.5 M solution in decane, 0.8 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the mono-epoxide (>90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3n** (26.8 mg, 90% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 (m, 2H), 7.35 (t, *J* = 7.6 Hz, 2H), 7.30 – 7.28 (m, 1H), 6.08 (s, 1H), 4.35 (s, 1H), 4.29 (d, *J* = 2.7 Hz, 1H), 2.68 (d, *J* = 3.1 Hz, 1H), 1.36 (s, 6H), 1.35 (s, 6H), 1.12 (s, 9H), 1.06 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 154.4, 136.4, 127.8, 127.1, 126.5, 83.7, 80.6, 65.5, 60.0,

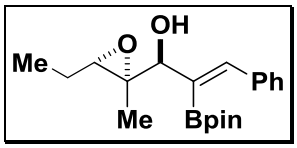
34.2, 30.1, 25.2, 25.0, 14.2 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 30.5.



(*E*)-1-(2-Hexyl-3-phenyloxiran-2-yl)-3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-2-en-1-ol (3m). The product was prepared by General Procedure B using bis-allylic alcohol **1m** (0.35 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (51.0 μL, ~5.5 M solution in decane, 0.28 mmol, 0.8 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the mono-epoxide (0.11 g, 86% ^{1}H NMR yield with internal standard CH_2Br_2, >90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3m** (90.6 mg, 70% yield). ^{1}H NMR (500 MHz, $CDCl_3$); 7.46 – 7.27 (m, 10H), 7.15 (s, 1H), 4.67 (d, *J* = 3.9 Hz, 1H), 4.37 (s, 1H), 2.89 (d, *J* = 4.5 Hz, 1H), 1.50 – 1.44 (m, 2H), 1.35 (s, 6H), 1.31 (s, 6H), 1.25 – 1.06 (m, 8H), 0.82 (t, *J* = 7.1 Hz, 3H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 143.1, 137.9, 136.4, 128.7, 128.2, 128.1, 128.0, 127.4, 126.7, 84.1, 77.7, 68.3, 60.7, 31.6, 29.6, 26.8, 25.1, 24.8, 22.6, 14.2 (the quaternary vinyl C bearing the boron is not observed); $^{11}B\{^{1}H\}$ NMR ($CDCl_3$,128 MHz) δ 30.1; IR (neat) 3470, 3027, 2977, 2955, 2929, 2858, 1626, 1602, 1496, 1455, 1391, 1310, 1250, 1143 cm^{-1}; HRMS *m/z* 485.2822 $[(M+Na)^{+}$; calcd for $C_{29}H_{39}BO_4Na$: 485.2839].

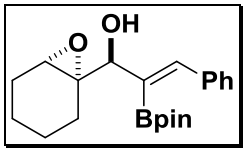


(*E*)-1-(3-Ethyl-2-methyloxiran-2-yl)-4,4--dimethyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pent-2-en-1-ol (3n). The product was prepared by General Procedure B using bis-allylic alcohol **1n** (0.91 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.12 mL, ~5.5 M solution in decane, 0.7 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the mono-epoxide (0.15 g, 75% yield ^{1}H NMR yield with internal standard CH_2Br_2, >90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3n** (0.13 g, 63% yield). ^{1}H NMR (500 MHz, $CDCl_3$); δ 6.02 (s, 1H), 4.09 (d, *J* = 3.3 Hz, 1H), 3.08 (dd, *J* = 7.4, 5.2 Hz, 1H), 2.52 (d, *J* = 3.4 Hz, 1H), 1.65 – 1.58 (m, 1H), 1.58 – 1.50 (m, 1H), 1.28 (s, 12H), 1.25 (s, 3H), 1.09 (s, 9H), 1.04 (t, *J* = 7.5 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 154.6, 83.8, 81.4, 63.4, 61.5, 34.4, 30.4, 25.5, 25.2, 21.8, 14.9, 11.0 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.2; IR (neat) 3480, 2969, 2875, 1639, 1464, 1411, 1373, 1305, 1255, 1144 cm^{-1}; HRMS *m/z* 347.2362 [$(M+Na)^+$; calcd for $C_{18}H_{33}BO_4Na$: 347.2370].



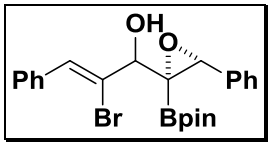
(*E*)-1-(3-Ethyl-2-methyloxiran-2-yl)-3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-2-en-1-ol (3o). The product was prepared by General Procedure B using bis-allylic alcohol **1o** (1.2 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.15 mL, ~5.5 M solution in decane, 0.7 equiv.). The TBHP solution was added slowly to the

reaction mixture over 30 min using a syringe pump. The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3o** (0.16 g, 54% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ7.38 (d, *J* = 6.5 Hz, 2H), 7.32 – 7.23 (m, 3H), 7.07 (s, 1H), 4.33 (s, 1H), 3.13 (t, *J* = 6.3 Hz, 1H), 2.75 (s, 1H), 1.68 – 1.54 (m, 2H), 1.36 (s, 3H), 1.28 (s, 6H), 1.26 (s, 6H), 1.07 (t, *J* = 7.5 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 142.9, 138.0, 128.6, 128.2, 128.0, 84.0, 80.6, 63.4, 61.6, 25.1, 24.9, 21.8, 14.7, 11.0 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128 MHz) δ 30.8; IR (neat) 3463, 3026, 2976, 2931, 2876, 1626, 1600, 1493, 1459, 1390, 1311, 1252, 1143 cm^{-1}; HRMS *m/z* 367.2054 [$(M+Na)^+$; calcd for $C_{20}H_{29}BO_4Na$: 367.2057].



(*E*)-1-(7-Oxabicycloheptan-1-yl)-3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)prop-2-en-1-ol (3p). The product was prepared by General Procedure B using bis-allylic alcohol **1p** (0.07 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (9.5 μL, ~5.5 M solution in decane, 0.7 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the mono-epoxide (>90% purity by ^{1}H NMR). The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **3p** (9.1 mg, 52% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ7.40 (d, *J* = 7.7 Hz, 2H), 7.33 – 7.22 (m, 3H), 7.08 (s, 1H), 4.31 (s, 1H), 3.40 – 3.26 (m, 1H), 2.70 (s, 1H), 2.04 – 1.81 (m, 4H), 1.51 – 1.40 (m, 2H), 1.36 – 1.22 (m, 14H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 143.3, 138.0, 128.7, 128.1, 128.0, 84.0, 80.2, 62.4, 56.4, 25.5, 25.2, 25.1, 24.5, 20.3, 20.0 (the quaternary vinyl C bearing the boron is not observed); ^{11}B{^{1}H} NMR ($CDCl_3$,128

MHz) δ 30.5; IR (neat) 3479, 3025, 2974, 2932, 2875, 1627, 1600, 1494, 1461, 1389, 1311, 1253, 1143cm^{-1}; HRMS *m/z* 379.2052 [(M+Na)$^+$; calcd for $C_{21}H_{29}BO_4Na$: 379.2057].

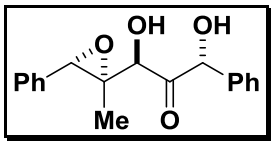


(*Z*)-2-Bromo-3-phenyl-1-(3-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)oxiran-2-yl)prop-2-en-1-ol (4q). The product was prepared by General Procedure B using bis-allylic alcohol **1q** (0.14 g, 0.31 mmol, 1 equiv.) and a solution of TBHP in 1 mL of CH_2Cl_2 (0.17 mL, ~5.5 M solution in decane, 3.0 equiv.). The TBHP solution was added slowly to the reaction mixture over 30 min using a syringe pump. The crude reaction mixture was filtered through a short pad of silica to afford the mono-epoxide. The product was further purified by flash column chromatography on silica gel (hexanes:EtOAc = 90:10) to afford the mono-epoxide **4q** (87.9 mg, 62% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.65 – 7.61 (m, 2H), 7.50 – 7.45 (m, 2H), 7.41 – 7.36 (m, 3H), 7.35 – 7.30 (m, 3H), 7.21 (s, 1H), 4.33 (s, 2H), 3.20 (s, 1H), 0.98 (s, 6H), 0.96 (s, 6H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 135.80, 135.28, 130.47, 129.39, 128.41, 128.33, 128.16, 128.11, 126.50, 125.94, 85.01, 79.40, 61.30, 24.73, 24.67 (the quaternary vinyl C bearing the boron is not observed); IR (neat) 3454, 3061, 3030, 2979, 2930, 1605, 1495, 1447, 1373, 1261, 1110, 1029 cm^{-1}; HRMS *m/z* 479.0996 [(M+Na)$^+$; calcd for $C_{23}H_{26}BBrO_4Na$: 479.1005].

General Procedure D: Synthesis of Epoxy-2-keto-*anti*-1,3-diols. To a 20 mL vial was added B(pin)-substituted bis-epoxide and 1 mL THF. The solution was cooled at 0 °C and solid $NaBO_3{\cdot}H_2O$ (3 equiv.) was added followed by 1 mL of H_2O. The reaction mixture was stirred and allowed to warm to rt. Stirring was continued until TLC showed consumption of the bis-

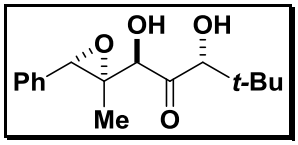
epoxide (4–6 h). The reaction mixture was then diluted with water (1 mL) and extracted with diethyl ether(3 x 10 mL). The combined organic layer was then washed with brine, dried over Na_2SO_4, and the solvent was removed under reduced pressure. The crude product was purified by flash chromatography on silica gel (hexanes:EtOAc = 80:20).

General Procedure E: Synthesis of Epoxy-2-keto-*anti*-1,3-diols. To a 20 mL vial was added B(pin)-substituted bis-epoxide and 2 mL THF. The solution was cooled at 0 °C and 30 % H_2O_2 (3.3 equiv.) and NaOH (1.1 equiv.) were added to the solution. The reaction mixture was stirred and allowed to warm to rt. Stirring was continued until TLC showed consumption of the bis-epoxides (2–4 h). The reaction mixture was then diluted with water (1 mL) and extracted with diethyl ether (4 x 10 mL). The combined organic layer was then washed with brine, dried over Na_2SO_4, and the solvent was removed under reduced pressure. The crude was purified by flash chromatography on silica gel (hexanes:EtOAc = 80:20).

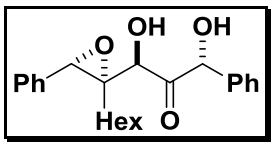


1,3-Dihydroxyl-1-(2-methyl-3-phenyloxiran-2-yl)-3-phenylpropan-2-one (5k). The product was prepared by General Procedure D using bis-epoxide **2k** (16.3 mg, 0.04 mmol) and $NaBO_3 \cdot H_2O$ (12.0 mg, 3 equiv., 0.12 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **5k** (9.3 mg, 78% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48 – 7.45 (m, 2H), 7.43 – 7.28 (m, 8H), 5.80 (s, 1H), 4.13 (s, 1H), 4.02 (s, 1H), 3.97 (s, 1H), 3.51 (s, 1H), 0.98 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 209.7, 137.4, 134.5, 129.3, 129.1, 128.4, 128.3, 127.8, 126.7, 78.3, 77.8,

64.3, 63.1, 11.1; IR (neat) 3469, 3030, 2979, 2928, 2854, 1714, 1600, 1495, 1452, 1380, 1145 cm^{-1}; HRMS *m/z* 321.1108 [$(M+Na)^+$; calcd for $C_{18}H_{18}O_4Na$: 321.1103].

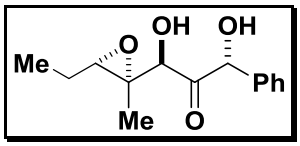


1,3-Dihydroxy-4,4-dimethyl-1-(2-methyl-3-phenyloxiran-2-yl)pentan-2-one (5l). The product was prepared by General Procedure D using bis-epoxide **2l** (23.7 mg, 0.06 mmol) and $NaBO_3 \cdot H_2O$ (18.0 mg, 3 equiv., 0.18 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **5l** (13.2 mg, 78% yield). ^1H NMR (500 MHz, $CDCl_3$) δ 7.53 (d, *J* = 7.2 Hz, 2H), 7.39 (t, *J* = 7.1 Hz, 2H), 7.34 (t, *J* = 7.2 Hz, 1H), 5.17 (s, 1H), 3.79 (s, 1H), 3.66 (s, 1H), 3.59 (s, 1H), 2.92 (s, 1H), 1.09 (s, 9H), 1.02 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 214.3, 139.0, 128.2, 128.1, 127.8, 85.1, 82.4, 76.8, 76.3, 35.2, 26.4, 18.8; IR (neat) 3427, 3062, 2979, 2928, 2855, 1712, 1600, 1480, 1409, 1380, 1304, 1144 cm^{-1}; HRMS *m/z* 301.1411 [$(M+Na)^+$; calcd for $C_{16}H_{22}O_4Na$: 301.1416].

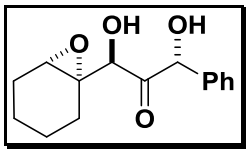


1-(2-Hexyl-3-phenyloxiran-2-yl)-1,3-dihydroxy-3-phenylpropan-2-one (5m). The product was prepared by General Procedure D using bis-epoxide **2m** (0.106 g, 0.22 mmol) and $NaBO_3 \cdot H_2O$ (65.9 mg, 3 equiv., 0.66 mmol). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **5m** (51.9 mg, 64% yield). ^1H NMR (500 MHz, $CDCl_3$) δ 7.47 – 7.43 (m, 2H), 7.42 – 7.31 (m, 6H), 7.26 – 7.21 (m, 2H), 5.82 (s, 1H), 4.10 (s, 1H), 4.05 (s, 1H), 3.87 (s, 1H), 3.39 (s, 1H), 1.60 – 1.51 (m, 1H), 1.43 – 1.32 (m, 1H), 1.22 – 1.14 (m, 2H), 1.13 – 1.06 (m, 6H), 0.82 (t, *J* = 7.2

Hz, 3H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ 210.2, 137.7, 134.6, 129.3, 129.1, 128.4, 128.3, 127.8, 126.7, 77.8, 77.6, 65.7, 64.6, 31.4, 29.5, 25.4, 24.8, 22.6, 14.2; IR (neat) 3460, 3064, 3033, 2956, 2926, 2856, 1715, 1600, 1495, 1455, 1379, 1263, 1012 cm^{-1}; HRMS *m/z* 391.1888 $[(M+Na)^+$; calcd for $C_{23}H_{28}O_4Na$: 391.1885].



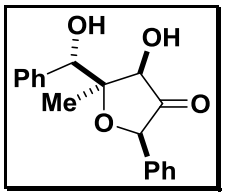
1-(3-Ethyl-2-methyloxiran-2-yl)-1,3-dihydroxy-3-phenylpropan-2-one (5o). The product was prepared by General Procedure E using bis-epoxide **2o** (80.0 mg, 0.22 mmol), NaOH (0.24 mmol, 1.1 equiv., 60 μL) and 30% H_2O_2 solution (0.73 mmol, 3.3 equiv., 22.5 μL). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **5o** (33.0 mg, 60% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.30 (m, 5H), 5.68 (d, *J* = 4.4 Hz, 1H), 4.13 (d, *J* = 6.2 Hz, 1H), 3.86 (d, *J* = 2.7 Hz, 1H), 3.34 (d, *J* = 3.8 Hz, 1H), 2.69 (t, *J* = 6.3 Hz, 1H), 1.62 – 1.47 (m, 2H), 1.15 (s, 3H), 1.02 (t, *J* = 7.5 Hz, 3H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$) δ210.1, 137.5, 129.2, 128.9, 127.7, 78.8, 77.7, 65.1, 60.6, 21.9, 12.0, 10.5; IR (neat) 3460, 3064, 3033, 2955, 2926, 2856, 1715, 1603, 1495, 1455, 1379, 1263, 1012 cm^{-1}; HRMS *m/z* 273.1092 $[(M+Na)^+$; calcd for $C_{14}H_{18}O_4Na$: 273.1103].



1-(7-Oxabicycloheptan-1-yl)-1,3-dihydroxy-3-phenylpropan-2-one (5p). The product was prepared by General Procedure E using bis-epoxide **2p** (70.8 mg, 0.27 mmol), NaOH (0.30 mmol, 1.1 equiv., 60 μL) and 30% H_2O_2 solution (0.89 mmol, 3.3 equiv., 27.4 μL).

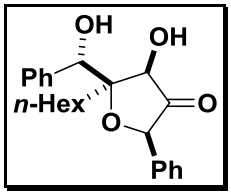
The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **5p** (43.2 mg, 61% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.42 – 7.31 (m, 5H), 5.68 (d, *J* = 5.6 Hz, 1H), 4.10 (d, *J* = 6.6 Hz, 1H), 3.87 (d, *J* = 3.5 Hz, 1H), 3.34 (d, *J* = 4.5 Hz, 1H), 2.95 (d, *J* = 2.7 Hz, 1H), 1.98 – 1.83 (m, 1H), 1.78 – 1.69 (m, 1H), 1.49 – 1.40 (m, 2H), 1.40 – 1.32 (m, 2H), 1.29 – 1.22 (m, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 209.8, 137.4, 129.2, 129.0, 127.8, 78.1, (one peak overlaps with the $CDCl_3$ peaks; two peaks are observed at 78.6, 78.0 in benzene-d_6) 60.0, 59.2, 24.6, 22.7, 20.1, 18.9; IR (neat) 3430, 2932, 2856, 1717, 1645, 1493, 1455, 1382, 1276, 1190, 1139 cm^{-1}; HRMS *m/z* 285.1100 [(M+Na)$^{+}$; calcd for $C_{15}H_{18}O_4Na$: 285.1103].

General Procedure F: Synthesis of Dihydroxy-dihydrofuran-3-(2*H*)-ones. In a 20 mL vial was added the epoxide-substituted keto-*anti*-1,3-diol (1 equiv., 0.05M) followed by dry THF, and the solution was cooled to 0 °C. Either neat $BF_3{\cdot}OEt_2$ or solid *p*-TsOH (1 equiv.) was added slowly to the solution. The reaction mixture was allowed to warm to rt and stirred at rt until TLC showed consumption of the epoxy keto diol (2–3 h). The reaction mixture was then diluted with water (1 mL) and extracted with diethyl ether(4 x 10 mL). The combined organic layer was then washed with brine, dried over Na_2SO_4, and the solvent was removed under reduced pressure. The crude was purified by flash chromatography on silica gel (hexanes:EtOAc = 80:20).

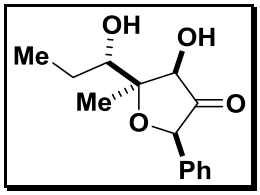


4-Hydroxy-5-(hydroxyl(phenyl)methyl)-5-methyl-2-phenyldihydrofuran-3-(2*H*)-one (6k). The product was prepared by General Procedure F using epoxide keto diol **5k**

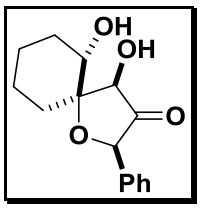
(43.3 mg, 0.15 mmol) and $BF_3{\cdot}OEt_2$ (0.15 mmol, 19.0 μL). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **6k** (40.3 mg, 90% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.55 – 7.51 (m, 2H), 7.51 – 7.47 (m, 2H), 7.45 – 7.32 (m, 6H), 5.26 (s, 1H), 5.02 (s, 1H), 4.05 (s, 1H), 3.96 (s, 1H), 3.07 (s, 1H), 1.18 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 211.4, 138.8, 136.2, 128.8, 128.7, 128.3, 128.3, 127.9, 127.0, 84.0, 79.9, 76.8, (one peak overlaps with the $CDCl_3$ peaks), 19.3; IR (neat) 3437, 3064, 3033, 2930, 1764, 1603, 1495, 1453, 1073, 1054, 1028 cm^{-1}; HRMS *m/z* 297.1136 [(M-H)$^-$; calcd for $C_{18}H_{17}O_4$: 297.1127].



5-Hexyl-4-hydroxy-5-(hydroxyl(phenyl)methyl-2-phenyldihydrofuran-3-2(H)-one (6m). The product was prepared by General Procedure F using epoxide keto diol **5m** (70.0 mg, 0.19 mmol) and $BF_3{\cdot}OEt_2$ (0.19 mmol, 24.0 μL). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **6m** (63.7 mg, 91% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.58 – 7.53 (m, 2H), 7.51 – 7.46 (m, 2H), 7.45 – 7.39 (m, 2H), 7.39 – 7.30 (m, 4H), 5.22 (s, 1H), 5.00 (s, 1H), 4.79 (s, 1H), 4.10 (s, 1H), 3.45 (s, 1H), 1.49 – 1.37 (m, 2H), 1.37 – 1.12 (m, 8H), 0.88 (t, *J* = 7.0 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 211.0, 138.8, 136.4, 128.9, 128.7, 128.6, 128.4, 128.1, 127.1, 85.5, 80.0, 78.1, 76.1, 33.1, 31.8, 29.8, 22.9, 22.7, 14.2; IR (neat) 3401, 3064, 3033, 2954, 2929, 2857, 1764, 1602, 1495, 1453, 1055, 1027 cm^{-1}; HRMS *m/z* 367.1927 [(M-H)$^-$; calcd for $C_{23}H_{27}O_4$: 367.1909].



4-Hydroxy-5-(1-hydroxypropyl)-5-methyl-phenyldihydrofuran-3(2*H*)-one (6o). The product was prepared by General Procedure F using epoxide keto diol **5o** (25.0 mg, 0.10 mmol) and *p*-TsOH (0.10 mmol, 19.4 mg). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **6o** (19.3 mg, 77% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.50 – 7.45 (m, 2H), 7.42 – 7.36 (m, 2H), 7.37 – 7.29 (m, 1H), 5.12 (s, 1H), 4.13 (s, 1H), 3.91 (s, 1H), 3.76 (dd, *J* = 10.6, 2.3 Hz, 1H), 2.78 (s, 1H), 1.84 – 1.72 (m, 1H), 1.67 – 1.54 (m, 1H), 1.43 (s, 3H), 0.99 (t, *J* = 7.4 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 211.3, 136.3, 128.8, 128.5, 126.6, 83.5, 78.8, 78.6, 77.6, 24.0, 20.2, 11.1; IR (neat) 3370, 3064, 3033, 2966, 2931, 2873, 1764, 1603, 1495, 1452, 1054 cm^{-1}; HRMS *m/z* 273.1095 [$(M+Na)^+$; calcd for $C_{14}H_{18}O_4Na$: 273.1103].



4,6-Dihydroxy-2-phenyl-1-oxaspiro[4,5]decan-3-one (6p). The product was prepared by General Procedure F using epoxide keto diol **5p** (13.1 mg, 0.05 mmol) and *p*-TsOH (0.05 mmol, 9.7 mg). The crude product was purified by flash column chromatography on silica gel (hexanes:EtOAc =80:20) to afford the 1,3-ketodiol **6p** (8.5 mg, 65% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.54 – 7.49 (m, 2H), 7.43 – 7.37 (m, 2H), 7.36 – 7.31 (m, 1H), 5.14 (s, 1H), 4.21 (s, 1H), 3.97 (dd, *J* = 8.9, 4.5 Hz, 1H), 3.73 (s, 1H), 2.50 (s, 1H), 2.07 – 1.93 (m, 2H), 1.88 – 1.76 (m, 3H), 1.74 – 1.66 (m, 1H), 1.63 – 1.54 (m, 1H), 1.48 – 1.39 (m, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ211.4, 136.5, 128.8, 128.4, 126.3, 83.3, 78.4, 78.3, (quaternary C is missing

or overlapping with the $CDCl_3$ peaks), 34.4, 30.6, 22.6, 22.4; IR (neat) 3402, 3065, 3033, 2934, 2863, 1767, 1603, 1495, 1455, 1157 cm^{-1}; HRMS *m/z* 261.1139 [[(M-H)$^-$; calcd for $C_{15}H_{17}O_4$: 261.1127].

References:

1. H. C. Brown, N. G. Bhat and M. Srebnik, *Tetrahedron Lett.*, 1988, **29**, 2631-2634.
2. M. Kim and D. Lee, *Org. Lett.*, 2005, **7**, 1865.
3. H. C. Brown and J. A. Sinclair, *J. Organomet. Chem.*, 1977, **131**, 163-169.
4. M. W. Büttner, J. B. Nätscher, C. Burschka and R. Tacke, *Organometallics*, 2007, **26**, 4835-4838.
5. E. C. Hansen and D. Lee, *J. Am. Chem. Soc.*, 2005, **127**, 3252-3253.
6. M. M. Hussain, H. Li, N. Hussain, M. Ureña, P. J. Carroll and P. J. Walsh, *J. Am. Chem. Soc.*, 2009, **131**, 6516.
7. M. M. Hussain and P. J. Walsh, *Angew. Chem., Int. Ed.*, 2010, **49**, 1834-1837.
8. M. M. Hussain, J. H. Toribio, P. J. Carroll and P. J. Walsh, *Angew. Chem., Int. Ed.*, 2011, **50**, 6337.
9. J. Renaud, C.-D. Graf and L. Oberer, *Angew. Chem., Int. Ed. Engl.*, 2000, **39**, 3101.
10. A. Pelter, B. Singaram and J. W. Wilson, *Tetrahedron Lett.*, 1983, **24**, 635-636.
11. A. Pelter, D. Buss and A. Pitchford, *Tetrahedron Lett.*, 1985, **26**, 5093-5096.
12. A. R. Katritzky, Z. Wang, H. Lang and D. Feng, *J. Org. Chem.*, 1997, **62**, 4125-4130.
13. K. Kaneda, Y. Kawanishi, K. Jitsukawa and S. Teranishi, *Tetrahedron Lett.*, 1983, **24**, 5009-5010.
14. T. Hirao, *Chem. Rev.*, 1997, **97**, 2707-2724.