Supporting Information

Intermolecular Bromoesterification of Conjugated Enynes: An Efficient Synthesis of Bromoallenes

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General remarks

All reactions in non-aqueous media were conducted under a positive pressure of dry argon in glassware that had been oven dried prior to use unless noted otherwise. Anhydrous solutions of reaction mixtures were transferred via an oven dried syringe or cannula. All solvents were dried prior to use unless noted otherwise. Thin layer chromatography was performed using precoated silica gel plates (EMD Chemical Inc. 60, F254). Flash column chromatography was performed with silica gel (Silicycle, 40-63 μm). Infrared spectra (IR) were obtained on a Bruker Equinox 55 Spectrophotometer. 1H and 13C nuclear magnetic resonance spectra (NMR) were obtained on a Varian Unity-Inova 400 MHz or 500 MHz recorded in ppm (δ) downfield of TMS (δ = 0) in CDCl3 unless noted otherwise. Signal splitting patterns were described as singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), or multiplet (m), with coupling constants (J) in hertz. High resolution mass spectra (HRMS) were performed by Analytical Instrument Center at the School of Pharmacy or Department of Chemistry on an Electron Spray Injection (ESI) mass spectrometer.

General methods for the preparation of conjugated enynes:

Substrates 3a, 3c, 3e, 3g, 3h were prepared according to our previously reported procedures1 and their spectra are in accordance with literature.1-4 Substrates 3b, 3d,6 and 3f7 were prepared according to known procedures and their spectra are in accordance with literature.

Characterization data for bromoesterification products:

2a: 5-bromo-1-hydroxypenta-3,4-dien-2-yl benzoate

Colorless oil. 21.0 mg, 73% yield. (dr = 10:1, 68% yield for 1mmol scale) 1H NMR (400 MHz, CDCl3, TMS): δ 8.07 (d, J = 7.2 Hz, 2H), 7.59 (t, J = 7.2 Hz, 1H), 7.46 (t, J = 7.6 Hz, 2H), 6.18 – 6.08 (dd, J = 5.6,
2.0 Hz, 1H), 5.69 (qd, J = 5.2, 2.0 Hz, 1H), 5.58 (t, J = 5.6 Hz, 1H), 3.91 (br, s, 2H), 2.10 (br, s, 1H). $^1$C NMR (100 MHz, CDCl$_3$): δ 202.57, 166.03, 133.54, 129.92, 129.68, 128.61, 97.04, 75.28, 71.57, 64.22. IR (neat) v 3454, 3061, 2934, 1719, 1265, 1069 cm$^{-1}$. HRMS (ESI) for C$_{12}$H$_{11}$BrO$_3$ (M+H), 282.9965 (Calc.), found 282.9967.

2b: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 2-methylbenzoate
Colorless oil. 19.0 mg, 65% yield. $^1$H NMR (500 MHz, CDCl$_3$, TMS): δ 7.96 (d, J = 8.0 Hz, 1H), 7.43 (td, J = 7.5, 0.5 Hz, 1H), 7.29 – 7.23 (m, 2H), 6.14 (dd, J = 5.5, 2.0 Hz, 1H), 5.70 – 5.63 (m, 1H), 5.58 (t, J = 5.5 Hz, 1H), 3.98 – 3.86 (m, 2H), 2.61 (s, 3H), 2.03 (s, 1H). $^1$C NMR (100 MHz, CDCl$_3$): δ 202.63, 166.82, 140.67, 132.57, 131.93, 130.91, 129.02, 125.95, 97.12, 75.30, 71.36, 64.26, 21.95. IR (neat) ν 3425, 3060, 2927, 1719, 1250, 1073 cm$^{-1}$. HRMS (ESI) for C$_{13}$H$_{13}$BrO$_3$ (M+H), 314.0387 (Calc.), found 314.0384.

2c: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 4-methylbenzoate
Colorless oil. 19.0 mg, 65% yield. $^1$H NMR (500 MHz, CDCl$_3$, TMS): δ 7.95 (d, J = 8.4 Hz, 2H), 7.27 (d, J = 7.0 Hz, 2H), 6.12 (dd, J = 5.6, 2.0 Hz, 1H), 5.68 (m, 1H), 5.56 (t, J = 5.6 Hz, 1H), 3.98 – 3.85 (m, 2H), 2.42 (s, 3H), 1.25 (s, 1H). $^1$C NMR (100 MHz, CDCl$_3$): δ 202.56, 166.10, 144.37, 129.98, 129.34, 126.93, 97.17, 75.26, 71.41, 64.32, 21.86. IR (neat) ν 3440, 3060, 2924, 1719, 1268, 1105 cm$^{-1}$. HRMS (ESI) for C$_{13}$H$_{13}$BrO$_4$ (M+H), 313.0387 (Calc.), found 313.0384.

2d: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 4-methoxybenzoate
Colorless oil. 14.0 mg, 45% yield. $^1$H NMR (500 MHz, CDCl$_3$, TMS): δ 8.02 (d, J = 9.0 Hz, 2H), 6.93 (d, J = 8.5 Hz, 2H), 6.12 (d, J = 5.5 Hz, 1H), 5.67 (d, J = 5.0 Hz, 1H), 5.58 (t, J = 5.5 Hz, 1H), 3.92 (d, J = 4.5 Hz, 2H), 3.87 (s, 3H), 2.02 (s, 1H). $^1$C NMR (100 MHz, CDCl$_3$): δ 202.53, 165.77, 163.89, 132.04, 122.01, 113.89, 97.27, 75.23, 71.31, 64.38, 55.64. IR (neat) ν 3453, 3060, 2923, 1711, 1254, 1101 cm$^{-1}$. HRMS (ESI) for C$_{13}$H$_{13}$BrO$_4$ (M+H), 313.0070 (Calc.), found 313.0066.
2e: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 4-fluorobenzoate. 
Colorless oil. 21.0 mg, 70% yield. 
$^1$H NMR (400 MHz, CDCl$_3$, TMS): δ 8.05 – 8.12 (m, 2H), 7.17 – 7.08 (t, $J = 8.4$ Hz, 2H), 6.13 (ddd, $J = 5.6, 2.0, 0.4$ Hz, 1H), 5.72 – 5.64 (m, 1H), 5.57 (td, $J = 5.6, 0.4$ Hz, 1H), 3.98 – 3.88 (m, 2H), 2.00 (s, 1H). 
$^{13}$C NMR (100 MHz, CDCl$_3$): δ 202.62, 166.17 (d, $J = 253$ Hz), 165.06, 132.54 (d, $J = 9.3$ Hz), 125.95, 115.84 (d, $J = 21.9$ Hz), 96.93, 75.33, 71.69, 64.22. IR (neat) ν 3440, 3061, 2927, 1720, 1265, 1113 cm$^{-1}$. HRMS (ESI) for C$_{12}$H$_{10}$BrFO$_3$ (M+Na), 322.9689 (Calc.), found 322.9690.

2f: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 4-chlorobenzoate. 
Colorless oil. 14.0 mg, 45% yield. $^1$H NMR (500 MHz, CDCl$_3$, TMS): δ 8.01 (d, $J = 8.5$ Hz, 2H), 7.45 (d, $J = 8.5$ Hz, 2H), 6.13 (dd, $J = 5.5, 2.0$ Hz, 1H), 5.73 – 5.62 (m, 1H), 5.58 (t, $J = 5.5$ Hz, 1H), 3.99 – 3.85 (m, 2H), 2.00 (s, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$): δ 202.65, 165.17, 140.09, 131.33, 129.01, 128.15, 96.85, 75.37, 71.79, 64.19. IR (neat) ν 3441, 3060, 2924, 1718, 1265, 1091 cm$^{-1}$. HRMS (ESI) for C$_{12}$H$_{10}$BrO$_3$ (M+Na), 338.9394 (Calc.), found 338.9392.

2g: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 4-bromobenzoate. 
Colorless oil. 16.0 mg, 44% yield. $^1$H NMR (400 MHz, CDCl$_3$, TMS): δ 7.93 (d, $J = 8.4$ Hz, 2H), 7.61 (d, $J = 8.4$ Hz, 2H), 6.13 (dd, $J = 6.0, 0.8$ Hz, 1H), 5.72 – 5.65 (m, 1H), 5.57 (t, $J = 6.0$ Hz, 1H), 3.98 – 3.90 (m, 2H), 1.99 (s, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$): δ 202.65, 165.31, 132.01, 131.44, 128.78, 128.61, 96.83, 75.38, 71.81, 64.18. IR (neat) ν 3424, 3060, 2923, 1720, 1265, 1116 cm$^{-1}$. HRMS (ESI) for C$_{12}$H$_{10}$Br$_2$O$_3$ (M+Na), 382.8888 (Calc.), found 382.8878.

2h: 5-bromo-1-hydroxypenta-3,4-dien-2-yl acetate.
Colorless oil. 15.0 mg, 67% yield. $^1$H NMR (500 MHz, CDCl$_3$, TMS): $\delta$ 6.17 – 6.11 (m, 1H), 5.47 (t, $J = 5.5$ Hz, 1H), 5.45 – 5.39 (m, 1H), 3.88 – 3.72 (m, 2H), 2.18 – 2.08 (s, 3H), 1.86 (s, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 202.59, 170.40, 96.84, 75.02, 71.14, 64.04, 21.12. IR (neat) $\nu$ 3441, 3060, 2924, 1737, 1232, 1044 cm$^{-1}$. HRMS (ESI) for C$_7$H$_9$BrO$_3$ (M+NH$_4$), 238.0074 (Calc.), found 238.0078.

2i: 5-bromo-1-hydroxypenta-3,4-dien-2-yl 2-phenylacetate.
Colorless oil. 23.0 mg, 77% yield. $^1$H NMR (400 MHz, CDCl$_3$, TMS): $\delta$ 7.38 – 7.27 (m, 5H), 6.03 – 5.95 (m, 1H), 5.47 – 5.37 (m, 2H), 3.77 (m, 2H), 3.69 (s, 2H), 1.71 (s, 1H). $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 202.43, 170.97, 133.69, 129.37, 128.83, 127.44, 96.72, 75.23, 71.34, 63.98, 41.45. IR (neat) $\nu$ 3454, 3060, 2922, 1734, 1245, 1146 cm$^{-1}$. HRMS (ESI) for C$_{13}$H$_{13}$BrO$_3$ (M+NH$_4$), 314.0387 (Calc.), found 314.0395.

2j: 5-bromo-1-hydroxypenta-3,4-dien-2-yl propionate.
Colorless oil. 14.0 mg, 61% yield. $^1$H NMR (400 MHz, CDCl$_3$, TMS): $\delta$ 6.14 – 6.10 (m, 1H), 5.50 – 5.40 (m, 2H), 3.87 – 3.75 (m, 2H), 2.40 (q, $J = 7.6$ Hz, 2H), 1.26 (s, 1H), 1.21 – 1.13 (m, 3H). $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 202.52, 173.88, 97.02, 75.05, 70.87, 64.13, 27.73, 9.26. IR (neat) $\nu$ 3455, 3061, 2924, 1737, 1180, 1082 cm$^{-1}$. HRMS (ESI) for C$_8$H$_{11}$BrO$_3$ (M+NH$_4$), 252.0230 (Calc.), found 252.0234.

4a: 5-bromo-1-hydroxy-6,6-dimethylhepta-3,4-dien-2-yl benzoate.
Colorless oil. 24.0 mg, 71% yield. $^1$H NMR (400 MHz, CDCl$_3$, TMS): $\delta$ 8.07 (d, $J = 7.2$ Hz, 2H), 7.58 (td, $J = 8.0$, 1.2 Hz, 1H), 7.45 (t, $J = 7.6$ Hz, 2H), 5.70 – 5.62 (m, 1H), 5.45 (dd, $J = 5.2$, 1.2 Hz, 1H), 3.95 – 3.88 (m, 2H), 2.09 (s, 1H), 1.07 (s, 9H). $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 198.20, 166.16, 133.57, 130.03, 129.91, 128.66, 109.10, 94.74, 72.10, 64.40, 37.04, 31.17, 29.12, 28.99. IR (neat) $\nu$ 3442, 3063, 2969, 1721, 1267, 1113 cm$^{-1}$. HRMS (ESI) for C$_{16}$H$_{10}$BrO$_3$ (M+Na), 361.0410 (Calc.), found 361.0414.
4b: 5-bromo-1-hydroxy-5-(trimethylsilyl)penta-3,4-dien-2-yl benzoate.
Colorless oil. 25.0 mg, 71% yield. \(^1\)H NMR (400 MHz, CDCl\(_3\), TMS): \(\delta\) 8.06 (d, \(J = 8.8\) Hz, 2H), 7.58 (t, \(J = 7.2\) Hz, 1H), 7.45 (t, \(J = 7.6\) Hz, 2H), 5.70 – 5.62 (m, 1H), 5.31 (d, \(J = 5.2\) Hz, 1H), 3.97 – 3.83 (m, 2H), 2.04 (s, 1H), 0.09 (s, 9H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 203.76, 165.99, 133.49, 129.94, 129.83, 128.58, 91.75, 90.05, 71.65, 64.48. IR (neat) \(\nu\) 3440, 3063, 2958, 1721, 1266, 1112 cm\(^{-1}\). HRMS (ESI) for C\(_{15}\)H\(_{19}\)BrO\(_3\)Si (M+NH\(_4^+\)), 372.0626 (Calc.), found 372.0615.

4c: 5-bromo-1-hydroxy-undeca-3,4-dien-2-yl benzoate.
Colorless oil. 15.9 mg, 65% yield. \(^1\)H NMR (400 MHz, CDCl\(_3\), TMS): \(\delta\) 8.07 (d, \(J = 8.1\) Hz, 2H), 7.59 (t, \(J = 8.0\) Hz, 1H), 7.46 (t, \(J = 7.6\) Hz, 2H), 5.64 (dt, \(J = 6.1, 4.7\) Hz, 1H), 5.46 (dt, \(J = 5.5, 3.0\) Hz, 1H), 3.98 – 3.86 (m, 2H), 2.32 (td, \(J = 7.5, 2.9\) Hz, 2H), 1.46 – 1.11 (m, 8H), 0.84 (t, \(J = 6.9\) Hz, 3H). \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 199.73, 166.18, 133.55, 130.00, 129.92, 128.66, 96.83, 94.69, 72.25, 64.42, 37.66, 31.61, 28.43, 27.97, 22.65, 14.24. IR (neat) \(\nu\) 3442, 3064, 2956, 2928, 2857, 1721, 1268, 1114, 909, 733, 711 cm\(^{-1}\). HRMS (ESI) for C\(_{18}\)H\(_{23}\)BrO\(_3\) (M+Na), 389.0722 (Calc.), found 389.0728.
References:

2d
2f