Supporting Information

Diastereoselective Synthesis of 6-Trifluoromethyl-5,6-dihydropyrans via

Phosphine-Catalyzed [4+2] Annulation of α-Benzylallenoates with Ketones

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Part I Experimental Part

General Information

Unless otherwise indicated, all starting materials were obtained from commercial supplies and used as received. The allenes were prepared according to the method of Kwon. Anhydrous ether and THF were distilled from sodium and benzophenone. Anhydrous CH₂Cl₂ was distilled from CaH₂. All reactions utilizing air or moisture sensitive reagents were performed in oven-dried glasswares with magnetic stirring under nitrogen atmosphere. Column chromatograph was performed with silica gel 200~300 mesh. All ¹H NMR (300 MHz), ¹³C NMR (75 MHz) spectra were recorded on a Bruker-DMX 300 spectrometer in CDCl₃, with tetramethylsilane as an internal standard and reported in parts per million (ppm, δ). ¹H NMR spectroscopy splitting patterns were designated as singlet (s), doublet (d), triplet (t). Splitting patterns that could not be interpreted or easily visualized were designated as multiplet (m) or broad (br). ¹⁹F NMR (376 MHz) spectra were recorded on a Bruker-DMX 400 spectrometer in CDCl₃. Infrared spectra were recorded on a JASCO FT/IR-480 spectrophotometer and reported as wave number (cm⁻¹).

1. Preparation of the allenes

Allenes 1a, 1b, 1c, 1d, 1e, 1g, 1h, 1i had been reported and the spectroscopic data are identical with those reported. Allene 1f was synthesized according to the procedures of Kwon’s report and the yield has not been optimized.
To a stirred solution of (carbethoxymethylene) triphenylphosphorane (5.0 g, 13.64 mmol, 1.0 eq) in anhydrous CHCl₃ was added 1-bromo-2-(bromomethyl)-
benzene (4.1 g, 16.37 mmol, 1.2 eq) at room temperature. The reaction mixture was
refluxed until (carbethoxymethylene) triphenylphosphorane was fully consumed.
The reaction mixture was cooled to room temperature, treated with Et₃N (3.0 g, 30.0
mmol, 2.2 eq), and stirred at room temperature for 1.5 h. Acetyl chloride (1.1 g, 13.64
mmol, 1.0 eq) was added dropwise over 30 min. The reaction mixture was stirred
overnight. The resulting mixture was poured into a Buchner funnel with a thin pad of
silica gel and was flushed with dichloromethane. The combined filtrate was
concentrated and the residue was subjected to a flash column chromatography on a
silica gel (petroleum ether/EtOAc = 50:1) to provide the allenoate 1f as colorless oil
(1.61 g, 5.73 mmol, 42% yield).

**Ethyl 2-(2-bromobenzyl)buta-2,3-dienoate.** Colorless oil; Rf = 0.7 (petroleum
ether/ethyl acetate = 20:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.53-7.50 (m, 1H),
7.28-7.19 (m, 2H), 7.09-7.03 (m, 1H), 5.02 (t, J = 3.0 Hz, 2H), 4.21 (q, J = 7.2 Hz,
2H), 3.70 (t, J = 3.0 Hz, 2H), 1.27 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ
214.4, 166.8, 138.2, 132.8, 128.2, 128.2, 127.3, 125.1, 99.2, 79.9, 61.3, 35.2, 14.3;
Anal. Calcd for C₁₃H₁₃BrO₂: C, 55.54; H, 4.66. Found: C, 55.54; H, 4.68; IR (KBr): ν
2982, 1967, 1709, 1470, 1440, 1366, 1257, 1215, 1076, 1025, 849, 754, 658 cm⁻¹.
2. PPh₃-catalyzed [4+2] annulation of α-benzylallenoates and ketones.

To a stirred solution of allene (0.5 mmol, 1.0 eq.) and trifluoromethylketone (0.75 mmol, 1.5 eq.) in CH₂Cl₂ (5 mL) was added Ph₃P (0.1 mmol, 0.2 eq.). The solution was refluxed until the full consumption of the allene. The reaction mixture was concentrated under reduced pressure, and the residue was purified by column chromatography on silica gel (petroleumether/EtOAc as the eluent, typically 40:1-20:1) to furnish the corresponding annulation product.

Ethyl 2,6-diphenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.

Reaction time: 72 hrs; Yield: 143 mg, 76%; white solid; mp 104-105 °C; Rᵣ = 0.6 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.43-7.18 (m, 2H), 7.24-7.18 (m, 8H), 7.09-7.05 (m, 1H), 5.72 (s, 1H), 4.03-3.82 (m, 2H), 3.22-3.12 (m, 1H), 2.84-2.77 (m, 1H), 0.97 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.7, 139.9, 138.8, 132.4, 132.2, 128.7, 128.5, 128.3, 128.1, 127.8, 126.5, 125.5 (q, J = 288 Hz), 75.4, 75.2 (q, J = 27 Hz), 60.6, 30.3, 13.9; ¹⁹F NMR (CDCl₃, 376 MHz) δ -75.27; IR (KBr): ν 2928, 1719, 1669, 1496, 1451, 1375, 1259, 1228, 1159, 1103,
1057, 889, 760, 699, 649 cm\(^{-1}\); HRMS (EI) calcd for C\(_{21}\)H\(_{19}\)F\(_3\)O\(_3\) [M]\(^+\) 376.1286, found 376.1289.

![Structure of 3ba](image)

**Ethyl 6-phenyl-2-p-tolyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.**

Reaction time: 66 hrs; Yield: 146 mg, 75%; white solid; mp 86-87 °C; R\(_f\) = 0.6 (petroleum ether/ethyl acetate = 10:1); \(^1\)H NMR (CDCl\(_3\), 300 MHz): \(\delta\) 7.50-7.49 (m, 2H), 7.29-7.27 (m, 3H), 7.22-7.20 (m, 2H), 7.13-7.07 (m, 3H), 5.77 (s, 1H), 4.11-3.92 (m, 2H), 3.28-3.19 (m, 1H), 2.90-2.83 (m, 1H), 2.31 (s, 3H), 1.07 (t, \(J = 7.2\) Hz, 3H);

\(^{13}\)C NMR (CDCl\(_3\), 75 MHz): \(\delta\) 164.9, 138.9, 138.0, 137.0, 132.6, 132.0, 129.0, 128.6, 128.4, 128.1, 126.5, 125.5 (q, \(J = 288\) Hz), 75.20 (q, \(J = 27\) Hz), 75.19, 60.6, 30.4, 21.3, 14.0; \(^{19}\)F NMR (CDCl\(_3\), 376 MHz) \(\delta\) -75.15; IR (KBr): \(\nu\) 2982, 1719, 1668, 1449, 1375, 1258, 1228, 1157, 1102, 1056, 1033, 969, 889, 816, 762, 728, 700, 647 cm\(^{-1}\); HRMS (EI) calcd for C\(_{22}\)H\(_{21}\)BrF\(_3\)O\(_3\) [M]\(^+\) 390.1443, found 390.1448.

![Structure of 3ca](image)

**Ethyl 2-(4-methoxyphenyl)-6-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-**
3-carboxylate. Reaction time: 60 hrs; Yield: 136 mg, 67%; white solid; mp 102-103 °C; R_f = 0.4 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.50-7.49 (m, 2H), 7.30 (m, 3H), 7.25-7.22 (m, 2H), 7.12 (dd, J₁ = 3.6 Hz, J₂ = 2.1 Hz, 1H), 6.82 (d, J = 8.1 Hz 2H), 5.75 (s, 1H), 4.11-3.96 (m, 2H), 3.79 (s, 3H), 3.29-3.20 (m, 1H), 2.91-2.85 (m, 1H), 1.09 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.9, 159.6, 138.9, 132.7, 132.1, 131.9, 129.6, 128.6, 128.1, 126.5, 125.5 (q, J = 288 Hz), 113.7, 75.2 (q, J = 27 Hz), 74.9, 60.6, 55.3, 30.3, 14.0; ¹⁹F NMR (CDCl₃, 376 MHz) δ -75.25; IR (KBr): v 2982, 2359, 1717, 1513, 1258, 1173, 1056, 700 cm⁻¹; HRMS (EI) calcd for C₂₂H₂₁F₃O₄ [M⁺] 406.1392, found 406.1395.

![Chemical structure](image)

Ethyl-2-(4-bromophenyl)-6-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3- carboxylate.

Reaction time: 92 hrs; Yield: 156 mg, 69%; white solid; mp 82-83 °C; R_f = 0.6 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.48 (t, J = 3.6 Hz, 2H), 7.42 (d, J = 8.4 Hz, 2H), 7.32-7.29 (m, 3H), 7.20-7.15 (m, 3H), 5.76 (s, 1H), 4.13-3.95 (m, 2H), 3.30-3.21 (m, 1H), 2.92-2.86 (m, 1H), 1.10 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.5, 139.1, 138.5, 132.7, 131.9, 131.5, 130.2, 128.8, 128.2, 126.5, 125.4 (q, J = 288 Hz), 122.3, 75.3 (q, J = 27 Hz), 74.8, 60.8, 30.3, 14.0; ¹⁹F NMR (CDCl₃, 376 MHz) δ -75.38; IR (KBr): v 2928, 2359, 1719, 1669, 1592, 1486, 1449, 1375, 1295, 1260, 1228, 1159, 1102, 1057, 1013, 970, 890, 849, 821, 763,
736, 700, 654 cm⁻¹; HRMS (EI) calcd for C₂₁H₁₈BrF₃O₃ [M]⁺ 454.0391, found 454.0387.

Ethyl 2-(3-bromophenyl)-6-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.

Reaction time: 66 hrs; Yield: 147 mg, 65%; white solid; mp 95-96 °C; Rₐ = 0.6 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.49-7.47 (m, 2H), 7.43-7.39 (m, 2H), 7.30-7.22 (m, 4H), 7.20-7.12 (m, 2H), 5.75 (s, 1H), 4.12-3.96 (m, 2H), 3.30-3.21 (m, 1H), 2.94-2.87 (m, 1H), 1.08 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.4, 142.1, 138.3, 133.0, 131.7, 131.5, 131.4, 129.9, 128.8, 128.1, 127.2, 126.5, 125.4 (q, J = 288 Hz), 122.22, 75.2 (q, J = 27 Hz), 74.7, 60.8, 30.1, 13.9; ¹⁹F NMR (CDCl₃, 376 MHz) δ -75.40; IR (KBr): ν 2982, 2359, 1718, 1669, 1474, 1430, 1375, 1295, 1265, 1228, 1158, 1104, 1057, 890, 786, 763, 701, 649 cm⁻¹; HRMS (EI) calcd for C₂₁H₁₈BrF₃O₃ [M]⁺ 454.0391, found 454.0396.

Ethyl 2-(2-bromophenyl)-6-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.

Reaction time: 92 hrs; Yield: 194 mg, 85%; colorless oil; Rₐ = 0.4 (petroleum
ether/ethyl acetate = 10:1); $^1$H NMR (CDCl$_3$, 300 MHz): $\delta$ 7.61-7.58 (m, 1H), 7.48 (m, 2H), 7.29-7.24 (m, 4H), 7.13-7.09 (m, 2H), 7.05-7.02 (m, 1H), 6.27 (s, 1H), 4.09-3.93 (m, 2H), 3.29-3.20 (m, 1H), 2.96-2.88 (m, 1H), 1.00 (t, $J = 7.2$ Hz, 3H); $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 164.5, 138.9, 138.3, 134.0, 133.1, 131.4, 129.8, 129.2, 128.7, 128.0, 127.5, 126.6, 125.4 (q, $J = 288$ Hz), 125.2, 75.3 (q, $J = 27$ Hz), 73.9, 60.7, 30.1, 13.8; $^{19}$F NMR (CDCl$_3$, 376 MHz) $\delta$ -75.50; IR (KBr): $\nu$ 2359, 1718, 1669, 1448, 1375, 1255, 1228, 1156, 1055, 1028, 758, 700 cm$^{-1}$; HRMS (ESI) calcd for C$_{21}$H$_{19}$BrF$_3$O$_3$ [M+1]$^+$ 455.0470, found 455.0459.

![Ethyl 6-phenyl-2-o-tolyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate](image.png)

Ethyl 6-phenyl-2-o-tolyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.

Reaction time: 70 hrs; Yield: 132 mg, 65%; colorless oil; $R_f = 0.6$ (petroleum ether/ethyl acetate = 10:1); $^1$H NMR (CDCl$_3$, 300 MHz): $\delta$ 7.46 (m, 2H), 7.28-7.25 (m, 3H), 7.21-7.17 (m, 3H), 7.06-7.00 (m, 2H), 6.04 (s, 1H), 4.10-3.90 (m, 2H), 4.08-3.92 (m, 1H), 2.93-2.85 (m, 1H), 2.53 (s, 3H), 1.00 (t, $J = 7.2$ Hz, 3H); $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 165.0, 138.6, 137.7, 137.3, 132.8, 132.3, 130.7, 128.7, 128.3, 128.1, 127.8, 126.6, 126.0, 125.6 (q, $J = 288$ Hz), 75.2 (q, $J = 27$ Hz), 71.98, 60.6, 30.2, 19.1, 13.9; $^{19}$F NMR (CDCl$_3$, 376 MHz) $\delta$ -75.37; IR (KBr): $\nu$ 2982, 1718, 1669, 1375, 1258, 1228, 1155, 1055, 760, 699 cm$^{-1}$; HRMS (EI) calcd for C$_{22}$H$_{21}$BrF$_3$O$_3$ [M]$^+$ 390.1443, found 390.1448.
**Ethyl 2-phenyl-6-p-toly1-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.** Reaction time: 84 hrs; Yield: 129 mg, 66%; white solid, mp 112-113 °C; R_f = 0.6 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.38 (d, J = 8.1 Hz, 2H), 7.32-7.25 (m, 5H), 7.15-7.13 (m, 1H) , 7.09 (d, J = 8.1 Hz, 2H), 5.79 (s, 1H), 4.09-3.93 (m, 2H), 3.28-3.18 (m, 1H), 2.90-2.84 (m, 1H), 2.30 (s, 3H), 1.05 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.8, 140.0, 138.5, 135.9, 132.4, 132.3, 128.8, 128.5, 128.28, 128.25, 125.6 (q, J = 288 Hz), 75.3, 75.1 (q, J = 27 Hz), 60.6, 30.4, 21.1, 13.9; ¹⁹F NMR (CDCl₃, 376 MHz) δ -75.36; IR (KBr): ν 2982, 1719, 1669, 1515, 1455, 1375, 1259, 1231, 1157, 1103, 1056, 1028, 970, 891, 846, 813, 749, 724, 698, 666, 600 cm⁻¹; HRMS (EI) calcd for C₂₂H₂₁F₃O₃ [M]⁺ 390.1443, found 390.1448.

**Ethyl 6-(4-methoxyphenyl)-2-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.** Reaction time: 96 hrs; Yield: 107 mg, 53%; colorless oil; R_f = 0.4
(petroleum ether/ethyl acetate = 10:1); ^1^H NMR (CDCl₃, 300 MHz): δ 7.40 (d, J = 8.4 Hz, 2H), 7.29-7.26 (m, 5H), 7.16-7.14 (m, 1H), 6.80 (d, J = 9.0 Hz, 2H), 5.78 (s, 1H), 4.11-3.91 (m, 2H), 3.74 (s, 3H), 3.26-3.17 (m, 1H), 2.91-2.84 (m, 1H), 1.05 (t, J = 7.2 Hz, 3H); ^1^C NMR (CDCl₃, 75 MHz): δ 164.8, 159.8, 140.0, 132.3, 130.7, 128.5 (2C), 128.27, 128.23, 127.9, 125.5 (q, J = 288 Hz), 113.4, 75.3, 75.0 (q, J = 27 Hz), 60.6, 55.3, 30.3, 13.9; ^1^9^F NMR (CDCl₃, 376 MHz) δ -75.68; IR (KBr): ν 2925, 1719, 1612, 1573, 1455, 1375, 1258, 1157, 1056, 828, 698 cm⁻¹; HRMS (EI) calcd for C₂₂H₂₁F₃O₄ [M]^+ 406.1392, found 406.1396.

**Ethyl 6-(4-chlorophenyl)-2-phenyl-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.**

Reaction time: 84 hrs; Yield: 175 mg, 85%; colorless oil; Rᶠ = 0.6 (petroleum ether/ethyl acetate = 10:1); ^1^H NMR (CDCl₃, 300 MHz): δ 7.43 (d, J = 7.8 Hz, 2H), 7.29-7.25 (m, 7H), 7.16-7.13 (m, 1H), 5.78 (s, 1H), 4.12-3.92 (m, 2H), 3.28-3.19 (m, 1H), 2.88-2.82(m, 1H), 1.06 (t, J = 7.2 Hz, 3H); ^1^C NMR (CDCl₃, 75 MHz): δ 164.6, 139.7, 137.2, 134.8, 132.4, 131.9, 131.5 (q, J = 2 Hz), 128.9 (q, J = 40 Hz), 128.40, 128.35, 128.27, 125.2 (q, J = 289 Hz), 75.5, 75.0 (q, J = 27 Hz), 60.7, 30.1, 13.9; ^1^9^F NMR (CDCl₃, 376 MHz) δ -75.49; IR (KBr): ν 2982, 1719, 1669, 1493, 1455, 1375, 1296, 1259, 1228, 1198, 1161, 1095, 1057, 1015, 969, 891, 823, 753, 733, 698, 662, 599 cm⁻¹; HRMS (EI) calcd for C₂₂H₁₈ClF₃O₃ [M]^+ 410.0897, found
**Ethyl 2-phenyl-6-(thiophen-2-yl)-6-(trifluoromethyl)-5,6-dihydro-2H-pyran-3-carboxylate.**

Reaction time: 84 hrs; Yield: 110 mg, 58%; white solid, mp 82-83 °C; Rf = 0.6 (petroleum ether/ethyl acetate = 10:1); ¹H NMR (CDCl₃, 300 MHz): δ 7.27-7.22 (m, 5H), 7.19 (dd, J₁ = 5.1 Hz, J₂ = 0.9 Hz, 1H), 7.16-7.13 (m, 1H), 7.00-6.99 (m, 1H), 6.87 (dd, J₁ = 5.1 Hz, J₂ = 3.6 Hz, 1H), 5.78 (s, 1H), 4.09-3.94 (m, 2H), 3.21-3.12 (m, 1H), 3.01-2.93 (m, 1H), 1.05 (t, J = 7.2 Hz, 3H); ¹³C NMR (CDCl₃, 75 MHz): δ 164.6, 141.8, 139.4, 132.1, 128.3, 128.2 (2C), 126.7, 126.1, 126.0 (q, J = 1.5 Hz), 124.9 (q, J = 287 Hz), 75.4, 75.0 (q, J = 29 Hz), 60.7, 40.0, 13.9; ¹⁹F NMR (CDCl₃, 376 MHz) δ -76.86; IR (KBr): ν 2982, 2359, 1719, 1668, 1495, 1455, 1433, 1375, 1297, 1259, 1174, 1101, 1055, 953, 884, 853, 748, 698 cm⁻¹; HRMS (El) calcd for C₁₉H₁₇F₃O₃S [M]+ 382.0850, found 382.0854.

**Ethyl 6-(perfluoroethyl)-2,6-diphenyl-5,6-dihydro-2H-pyran-3-carboxylate.**

Reaction time: 84 hrs; Yield: 93 mg, 44%; colorless oil; Rf = 0.6 (petroleum
ether/ethyl acetate = 10:1); $^1$H NMR (CDCl$_3$, 300 MHz): $\delta$ 7.49-7.46 (m, 2H), 7.33-7.24 (m, 8H), 7.17-7.14 (m, 1H), 5.78 (s, 1H), 4.10-3.94 (m, 2H), 3.45-3.36 (m, 1H), 2.83-2.74 (m, 1H), 1.05 (t, $J$ = 7.2 Hz, 3H); $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 164.8, 140.0, 139.4, 139.3, 132.7, 131.91, 131.88, 128.50, 128.46, 128.40, 128.37, 128.1, 126.24, 126.20, 119.2 (qt, $J_1$ = 287 Hz, $J_2$ = 35 Hz), 115.5 (tq, $J_1$ = 265 Hz, $J_2$ = 35 Hz), 75.41, 75.35 (t, $J$ = 22 Hz), 60.7, 31.6, 13.9; $^{19}$F NMR (CDCl$_3$, 376 MHz) $\delta$ -78.55 (s, 3F), -114.35 (d, $J$ = 282 Hz, 1F), -120.73 (d, $J$ = 282 Hz, 1F); IR (KBr): $\nu$ 2982, 1720, 1671, 1496, 1450, 1375, 1348, 1258, 1258, 1219, 1167, 1132, 1074, 1051, 977, 881, 760, 699, 606, 538 cm$^{-1}$; HRMS (EI) calcd for C$_{22}$H$_{19}$F$_5$O$_3$ [M]$^+$ 426.1254, found 426.1259.

3. **Hydrogenation of the dihydropyran 3aa.**

![Chemical Structure](image)

To an oven-dried 50 mL Schlenk tube equipped with a stir bar was charged with 5% Pd/C (6 mg, 10% weight). This tube was closed with a septum, evacuated, and back-filled with hydrogen. To this mixture was added a methanol (6 mL) solution of the [4 + 2] Cycloaddition product 3aa (60 mg, 0.159 mmol). The mixture was vigorously stirred for 10 hrs at RT. The mixture was diluted with ethyl acetate and passed through a short kieselguhr pad. The solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel.
(petroleum ether/EtOAc = 20:1) to give the desired product as a colorless oil (48mg, 80% yield).

**Ethyl 2,6-diphenyl-6-(trifluoromethyl)-tetrahydro-2H-pyran-3-carboxylate.**

Reaction time: 20 hrs; Yield: 48 mg, 80%; colorless oil; Rf = 0.4 (petroleum ether/ethyl acetate = 10:1); \(^1\)H NMR (CDCl\(_3\), 300 MHz): \(\delta\) 7.62-7.59 (m, 2H), 7.44-7.30 (m, 8H), 5.23 (d, \(J = 10.5\) Hz, 1H), 3.95 (q, \(J = 7.2\) Hz, 2H), 2.86-2.77 (m, 1H), 2.70-2.62 (m, 1H), 2.36-2.23 (m, 1H), 2.12-2.00 (m, 2H), 1.01 (t, \(J = 7.2\) Hz, 3H); \(^13\)C NMR (CDCl\(_3\), 75 MHz): \(\delta\) 173.0, 140.2, 139.5 (q, \(J = 0.8\) Hz), 128.6, 128.5 (2C), 128.2, 127.4, 126.4, 126.2 (q, \(J = 288\) Hz), 76.94 (q, \(J = 1.5\) Hz), 76.90 (q, \(J = 27\) Hz), 60.7, 48.3, 28.1, 23.1, 14.1; \(^{19}\)F NMR (CDCl\(_3\), 376 MHz) \(\delta\) -73.13; IR (KBr): \(\nu\) 3035, 2980, 1730, 1496, 1449, 1376, 1296, 1152, 1032, 954, 898, 866, 763, 699, 642, 609 cm\(^{-1}\); HRMS (EI) calcd for C\(_{21}\)H\(_{17}\)F\(_3\)O\(_3\) [M]+ 378.1443, found 378.1447.

4. **X-ray structure of dihydropyran 3ea**

The crystal suitable for X-ray analysis was prepared by slow evaporation of the solvent of the solution of 3ea in methanol at room temperature. The crystal data are summarized in Table S1.

<table>
<thead>
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<th>Table S1. Crystal data and structure refinement for SA720 (3ea).</th>
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5. Determination of the relative configuration of tetrahydropyran 4aa

The relative configuration of tetrahydropyran 4aa was assigned by the coupling constant of the $^1$H NMR, the cosy and noesy 2D NMR spectra of 4aa.

The large coupling constant between $H^a$ and $H^b$ suggests the trans-configuration of these two protons (Figure S1).

![Figure S1](image_url)

**Figure S1** Coupling constant of $J_{Ha, Hb}$ of 4aa

The noesy spectrum of tetrahydropyran 4aa showed different NOEs of proton $H^a$ and $H^b$ (Figure S2). Proton $H^a$ showed strong NOEs with proton $H^f$ and $H^f$, while $H^b$ showed strong NOEs with proton $H^e$ and $H^e$. 

S14
References and notes:


Part II Copies of $^1$H, $^{13}$C and 2D NMR Spectra.
Current Data Parameters
NAME          wt-413-a1
EXPNO                20
PROCNO                1
F2 - Acquisition Parameters
Date_          20100429
Time               0.26
INSTRUM           spect
PROBHD   5 mm DUL 13C-1
F1PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                 1024
DS                    4
SWH           17985.611 Hz
FIDRES         0.274439 Hz
AQ            1.8219508 sec
RG               5160.6
DE                 8.00 usec
TE                297.3 K
D1           2.00000000 sec
D11          0.03000000 sec
TD0                   1

==== CHANNEL f1 ========
NUC1                13C
P1                12.50 usec
PL1                2.00 dB
SF1F               75.475295 MHz

==== CHANNEL f2 ========
CPDPRG2         waltz16
NUC2                 1H
PCPD2            100.00 usec
PL2                3.00 dB
PL12              22.33 dB
PL13              23.00 dB
SF2F               300.131200 MHz

F2 - Processing parameters
SI                32768
SF           75.4677470 MHz
WDW                  EM
SSB                   0
LB                 1.00 Hz
GB                    0
PC                 1.40
Current Data Parameters
NAME             wt-437
EXPNO                20

F2 - Acquisition Parameters
Date_          20100525
Time              17.02
INSTRUM           spect
PROBHD   5 mm DUL 13C-1
PULPROG          zg30
TD                65536
SOLVENT           CDCl3
NS                    7
DS                    0
SNH         8992.806 Hz
FIDRES          0.137219 Hz
AQ            3.6438515 sec
RG                45.3
DM                56.600 usec
DE                8.00 usec
TE                299.7 K
D1           1.00000000 sec
T00                   1

====== CHANNEL f1 ======
NUC1                1H
P1                10.80 usec
PL1                3.00 dB
SFO1         300.1324010 MHz

F2 - Processing parameters
SI                32768
SF           300.1300199 MHz
WDW                  EM
SSB                   0
LB                 0.30 Hz
GB                    0
PC                 1.00

Current Data Parameters
NAME             wt-437
EXPNO                31

F2 - Acquisition Parameters
Date_          20100525
Time              17.12
INSTRUM           spect
PROBHD   5 mm DUL 13C-1
PULPROG          zg30
TD                65536
SOLVENT           CDCl3
NS                  176
DS                    4
SNH         17985.611 Hz
FIDRES          0.274439 Hz
AQ            1.8219988 sec
RG                13004
DM                27.480 usec
DE                8.00 usec
TE                299.7 K
D1           2.00000000 sec
D11          0.03000000 sec
T00                   1

====== CHANNEL f1 ======
NUC1                13C
P1                12.50 usec
PL1                2.00 dB
SFO1         75.4752953 MHz

====== CHANNEL f2 ======
CPDPRG2         waltz16
NUC2                 1H
PL2                100.00 usec
PL12              22.33 dB
PL13              23.00 dB
SFO2        300.1312905 MHz

F2 - Processing parameters
SI                32768
SF           75.4677449 MHz
WDW                  EM
SSB                   0
LB                1.00 Hz
GB                    0
PC                 1.40

S22
3ae (exp no: wt-460)

Current Data Parameters
NAME         wt-460
EXPNO        11
PROCNO       1

F2 - Acquisition Parameters
Date_          20100619
Time              12.21
INSTRUM           spect
PROBHD   5 mm DUL 13C-1
PULPROG          zgpg30
TD                65536
SOLVENT           CDCl3
NS                  205
DS                    4
SWH           17985.611 Hz
FIDRES         0.274439 Hz
AQ            1.8219508 sec
RG               9195.2
DW               27.800 usec
DE                 8.00 usec
TE                299.8 K
D1           2.00000000 sec
D11          0.03000000 sec
D12                  1
D13                  1
D14                  1
D15                  1
D16                  1
D17                  1
D18                  1
D19                  1
D20                  1
D21                  1
D22                  1
D23                  1
D24                  1
D25                  1
D26                  1
D27                  1
D28                  1
D29                  1
D30                  1
D31                  1
D32                  1
D33                  1
D34                  1
D35                  1
D36                  1
D37                  1
D38                  1
D39                  1
D40                  1
D41                  1
D42                  1
D43                  1
D44                  1
D45                  1
D46                  1
D47                  1
D48                  1
D49                  1
D50                  1
D51                  1
D52                  1
D53                  1
D54                  1
D55                  1
D56                  1
D57                  1
D58                  1
D59                  1
D60                  1
D61                  1
D62                  1
D63                  1
D64                  1
D65                  1
D66                  1
D67                  1
D68                  1
D69                  1
D70                  1
D71                  1
D72                  1
D73                  1
D74                  1
D75                  1
D76                  1
D77                  1
D78                  1
D79                  1
D80                  1
D81                  1
D82                  1
D83                  1
D84                  1
D85                  1
D86                  1
D87                  1
D88                  1
D89                  1
D90                  1
D91                  1
D92                  1
D93                  1
D94                  1
D95                  1
D96                  1
D97                  1
D98                  1
D99                  1
D100                 1
D101                 1
D102                 1
D103                 1
D104                 1
D105                 1
D106                 1
D107                 1
D108                 1
D109                 1
D110                 1
D111                 1
D112                 1
D113                 1
D114                 1
D115                 1
D116                 1
D117                 1
D118                 1
D119                 1
D120                 1
D121                 1
D122                 1
D123                 1
D124                 1
D125                 1
D126                 1
D127                 1
D128                 1
D129                 1
D130                 1
D131                 1
D132                 1
D133                 1
D134                 1
D135                 1
D136                 1
D137                 1
D138                 1
D139                 1
D140                 1
D141                 1
D142                 1
D143                 1
D144                 1
D145                 1
D146                 1
D147                 1
D148                 1
D149                 1
D150                 1
D151                 1
D152                 1
D153                 1
D154                 1
D155                 1
D156                 1
D157                 1
D158                 1
D159                 1
D160                 1
D161                 1
D162                 1
D163                 1
D164                 1
D165                 1
D166                 1
D167                 1
D168                 1
D169                 1
D170                 1
D171                 1
D172                 1
D173                 1
D174                 1
D175                 1
D176                 1
D177                 1
D178                 1
D179                 1
D180                 1
D181                 1
D182                 1
D183                 1
D184                 1
D185                 1
D186                 1
D187                 1
D188                 1
D189                 1
D190                 1
D191                 1
D192                 1
D193                 1
D194                 1
D195                 1
D196                 1
D197                 1
D198                 1
D199                 1
D200                 1

F2 - Processing parameters
SSB                   0
LB                 1.00 Hz
SF                75.4574453 MHz
SNW                  0
SSB                  0
LB                 1.00 Hz
SF                75.4574453 MHz
PC                 1.40
EIIOOC

3aa (exp no: wt-428)

Current Data Parameters
NAME 175
EXPNO 1
PROCNO 1

F2 - Acquisition Parameters
Date_ 20100809
Time 14.03
INSTRUM AV400
PROBHD 5 mm BBO BB-1H
PULPROG zgflqn
TE 276.4
SOLVENT CDCl3
DS 0
SNK 70187.966 kHz
FIDRES 2.1784 kHz
AQ 4.66 sec
RG 35.9
DW 6.650 usec
DE 6.00 usec
TE 299.3 K
D1 1.00000000 sec

F2 - Processing parameters
SI 65536
SF 376.4983540 MHz
WDW EM
SSB 0
LB 10.00 Hz
GB 0
PC 0.10

------ CHANNEL f1 ------

NAME 19F
EXPNO 1
PROCNO 1

F1 - Acquisition Parameters
SNK 75187.966 kHz
FIDRES 2.1784 kHz
AQ 4.66 sec
RG 35.9
DW 6.650 usec
TE 299.3 K
D1 1.00000000 sec

F1 - Processing parameters
SI 65536
SF 376.4983540 MHz
WDW EM
SSB 0
LB 10.00 Hz
GB 0
PC 0.10
Current Data Parameters
NAME : 149
EXPNO : 1
PROCNO : 1

F2 - Acquisition Parameters
Date_ : 20100809
Time : 15.51
INSTRUM : AV400
PROBHD : 5 mm BBO BB-1H
PULPROG : zgflqn
TD : 32768
SOLVENT : CDCl3
NS : 16
DS : 0
SWH : 75187.969 Hz
AQ : 9.21750 Hz
RG : 35.9
DW : 6.650 us
DE : 6.00 us
TE : 299.4 K
D1 : 1.000000 sec

-------- CHANNEL f1 --------
NUC1 : 19F
P1 : 12.50 us
PL1 : 0.00 dB
SFO1 : 376.4607042 MHz

F2 - Processing parameters
SI : 65536
SF : 376.4983540 MHz
WDW : EM
SSB : 0
LB : 10.00 Hz
GB : 0
PC : 0.10

Current Data Parameters
NAME : 149
EXPNO : 1
PROCNO : 1

F2 - Acquisition Parameters
Date_ : 20100809
Time : 16.10
INSTRUM : AV400
PROBHD : 5 mm BBO BB-1H
PULPROG : zgflqn
TD : 32768
SOLVENT : CDCl3
NS : 16
DS : 0
SWH : 75187.969 Hz
AQ : 9.21750 Hz
RG : 35.9
DW : 6.650 us
DE : 6.00 us
TE : 299.2 K
D1 : 1.00000000 sec

-------- CHANNEL f1 --------
NUC1 : 19F
P1 : 12.50 us
PL1 : 0.00 dB
SFO1 : 376.4607042 MHz

F2 - Processing parameters
SI : 65536
SF : 376.4983540 MHz
WDW : EM
SSB : 0
LB : 10.00 Hz
GB : 0
PC : 0.10
3ac (exp no: wt-461)

Current Data Parameters
BAND: 141
PRONO: 1

F2 - Acquisition Parameters
Date_0: 20100809
Time: 16.11
INSTRUM: AV400
PROBHD: 5 mm BBO BB-1H
PULPROG: zgflqn
TD: 32768
SOLVENT: CDCl3
NS: 16
DS: 0
SWH: 75187.969 Hz
FIDRES: 2.294555 Hz
AQ: 0.2179572 sec
RG: 35.9
DW: 6.650 usec
DE: 6.00 usec
TE: 299.2 K
D1: 1.00000000 sec

======== CHANNEL f1 ========
NUC1: 19F
P1: 12.50 usec
PL1: 0.00 dB
SFO1: 376.4607047 MHz

F2 - Processing parameters
SI: 65536
SF: 376.4983540 MHz
WDW: EM
SSB: 0
LB: 10.00 Hz
GB: 0
PC: 0.10

3ad (exp no: wt-459)

Current Data Parameters
BAND: 141
PRONO: 1

F2 - Acquisition Parameters
Date_0: 20100809
Time: 16.04
INSTRUM: AV400
PROBHD: 5 mm BBO BB-1H
PULPROG: zgflqn
TD: 32768
SOLVENT: CDCl3
NS: 16
DS: 0
SWH: 75187.969 Hz
FIDRES: 2.294555 Hz
AQ: 0.2179572 sec
RG: 35.9
DW: 6.650 usec
DE: 6.00 usec
TE: 299.2 K
D1: 1.00000000 sec

======== CHANNEL f1 ========
NUC1: 19F
P1: 12.50 usec
PL1: 0.00 dB
SFO1: 376.4607047 MHz

F2 - Processing parameters
SI: 65536
SF: 376.4983540 MHz
WDW: EM
SSB: 0
LB: 10.00 Hz
GB: 0
PC: 0.10
3ae (exp no: wt-460)

Current Data Parameters
NAME                173
EXPNO                 1
PROCNO                1

F2 - Acquisition Parameters
Date_          20100809
Time              16.00
INSTRUM           AV400
PROBHD   5 mm BBO BB-1H
PULPROG          zgflqn
TD                32768
SOLVENT           CDCl3
NS                   16
DS                    0
SWH           75187.969 Hz
FIDRES         2.294555 Hz
AQ            0.2179572 sec
RG                 35.9
DW                6.650 usec
DE                 6.00 usec
TE                299.3 K
D1           1.00000000 sec

======== CHANNEL f1 ========
NUC1                19F
P1                12.50 usec
PL1                0.00 dB
SFO1        376.4607042 MHz

F2 - Processing parameters
SI                65536
SF          376.487142 MHz
WDW                  EM
SSB                   0
LB                10.00 Hz
GB                    0
PC                 0.10

3af (exp no: wt-499)

Current Data Parameters
NAME                174
EXPNO                 1
PROCNO                1

F2 - Acquisition Parameters
Date_          20100809
Time              16.01
INSTRUM           AV400
PROBHD   5 mm BBO BB-1H
PULPROG          zgflqn
TD                32768
SOLVENT           CDCl3
NS                   16
DS                    0
SWH           75187.969 Hz
FIDRES         2.294555 Hz
AQ            0.2179572 sec
RG                 35.9
DW                6.650 usec
DE                 6.00 usec
TE                299.3 K
D1           1.00000000 sec

======== CHANNEL f1 ========
NUC1                19F
P1                12.50 usec
PL1                0.00 dB
SFO1        376.4607042 MHz

F2 - Processing parameters
SI                65536
SF          376.487142 MHz
WDW                  EM
SSB                   0
LB                10.00 Hz
GB                    0
PC                 0.10
EtOOC₇-F₃C

4aa (exp no: wt-488)

Current Data Parameters
NAME                171
EXPNO                 1
PROCNO                1

F2 - Acquisition Parameters
Date_          20100809
Time              15.56
INSTRUM           AV400
PROBHD   5 mm BBO BB-1H
PULPROG          zgflqn
TD                32768
SOLVENT           CDCl3
NS                   16
DS              75187.969 Hz
PDRRES        2,294555 Hz
AQ                0.2375572 sec
B1                  14
DW             4.452 usec
DE                0.25 usec
TE                298.1 K
G1            1.006006829 sec

== Channel f1 ==
NUC1                19F
P1                12.50 usec
PL1                0.00 dB
SFO1        376.4607042 MHz

F2 - Processing parameters
SI                65536
SF          376.4983540 MHz
WDW                  EM
SSB                   0
LB                10.00 Hz
GB                    0
PC                 0.10