Construction of Optically Active CF₃-Containing Quaternary Carbon Centers via Stereospecific S_N2' Reaction

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Supporting information

Experimental:

General method

All manipulations involving air-sensitive materials were performed under argon, with such materials being exposed only to thoroughly dried and degassed solvent. Reagent and solvent were handled by using standard syringe techniques. Dehydrated diethyl ether, tetrahydrofuran (THF), and dichloromethane were purchased from Kanto Chemical Co., Inc., and used as they were. ¹H NMR spectra were recorded with a Varian Mercury-300 (300 MHz) or Varian VXR-500 (500 MHz), in CDCl₃ unless otherwise noted. Chemical Shifts were recorded in parts per million (ppm), downfield from internal tetramethylsilane (Me₄Si : δ 0.00). ¹³C NMR spectra were recorded with a Varian Mercury-300 (75 MHz), in CDCl₃ unless otherwise noted. Chemical Shifts were recorded in ppm, downfield from Me₄Si 0.00 Hz or the central CDCl₃ 77.000 Hz. ¹⁹F NMR were recorded with a Varian Mercury-300 (282 MHz) or Varian VXR-500 (470 MHz), in CDCl₃ unless otherwise noted. Chemical Shifts were recorded in ppm, downfield from initial hexafluorobenzene (C₆F₆). Data were tabulated in the following order: number of protons, multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; sex, sextet; sep, septet; oct, octet; m, multiplet; b, broad peak), coupling constants (in Hertz). When products were obtained as a mixture, only apparent peaks are described for minor products. Infrared (IR) spectra were obtained on a Perkin-Elmer FTIR-1650 spectrometer or Shimadzu FTIR-8400S spectrometer, and all spectra were reported in wave number (cm⁻¹). Optical rotations were measured on a JASCO DIP-1000 digital polarimeter. Specific rotations [α]_D, were reported in degrees and concentration (c) was given in grams per 100 mL of the indicated solvent. High performance liquid chromatography (HPLC) was performed on a Shimadzu LC-10AD liquid chromatograph equipped with DGU-12A degasser and SPD-10A uv-vis detector and all measurements used DAICEL CHIRALPAK AD. Column chromatography was conducted with silica gel (Fuji Silysia, BW-200) or aluminum oxide (Merck, 90 active neutral), by using a mixture of hexane and ethyl acetate (v/v).

General procedure of Hörner-Wadsworth-Emmons Reaction toward 3

Triethyl phosphonoacetate 10.9 mL (55.1 mmol) was added to a two-necked round-bottomed flask containing 1.454 g of NaH (60.6 mmol) in THF (110 mL) under an argon atmosphere at 0 °C. The resultant homogenous solution was stirred at that temperature for 30 min, and then **3** (55.1 mmol) was added and stirred at 0 °C for 30 min. The reaction mixture was quenched with water and extracted with ethyl acetate. The aqueous layer was further washed with ethyl acetate twice. The combined organic layer was washed with brine, dried (MgSO₄) and concentrated under vacuum and the resulting crude product was purified by silica gel column chromatography.

Ethyl 5-phenyl-3-(trifluoromethyl)-2-pentenoate (4a)

The desired product was obtained as an inseparable mixture of *E/Z*=84/16 in 92% yield.

IR (neat) ν 3058, 3024, 2982, 2948, 2357, 1727, 1454, 1310, 1165, 1129, 1030, 896, 732, 714, cm⁻¹; Anal. Calcd for C₁₄H₁₅ F₃O₂: C, 61.76; H, 5.55. Found: C, 61.63; H, 5.70. (*E*)-isomer: ¹H NMR δ 1.31 (3 H, t, *J*=7.3 Hz), 2.81-2.88 (2 H, m), 2.92-2.99 (2 H, m), 4.22 (2 H, q, *J*=7.1 Hz), 6.36 (1 H, q, *J*=1.6 Hz), 7.18-7.34 (5 H, aromatic); ¹³C NMR δ 14.11, 29.13, 35.09, 60.94, 122.51 (q, *J*=6.0 Hz), 123.46 (q, *J*=274.6 Hz), 126.15, 128.34, 128.39, 140.57, 145.05 (q, *J*=29.01 Hz), 164.19; ¹⁹F

NMR δ 92.61(s). **(Z)-isomer:** ^1H NMR δ 1.13 (3 H, t, $J=7.1$ Hz), 2.37-2.43 (2 H, m), 2.63-2.68 (2 H, m), 4.06 (2 H, q, $J=7.1$ Hz), 5.83 (1 H, t, $J=1.5$ Hz), 6.99-7.17 (5 H, aromatic); ^{13}C NMR δ 13.89, 33.39 (q, $J=2.0$ Hz), 33.81, 61.33, 122.42 (q, $J=275.4$ Hz), 125.34 (q, $J=3.7$ Hz), 126.31, 128.20, 128.42, 137.46 (q, $J=30.5$ Hz), 139.57, 164.28 (q, $J=1.1$ Hz); ^{19}F NMR δ 98.66 (s).

Ethyl 3-(trifluoromethyl)-2-undecenoate (4b)

The desired product was obtained as an inseparable mixture of $E/Z=81/19$ in 92% yield.

IR (neat) ν 2928, 2857, 1734, 1457, 1378, 1314, 1199, 1130, 1025, 895, 668 cm^{-1} ; Anal. Calcd for $\text{C}_{14}\text{H}_{23}\text{F}_3\text{O}_2$: C, 59.98; H, 8.27. Found: C, 58.49; H, 8.71. **(E)-isomer:** ^1H NMR δ 0.88-2.67 (20 H, m), 4.231 (2 H, q, $J=7.1$ Hz), 6.30 (1 H, q, $J=1.6$ Hz); ^{13}C NMR δ 14.15, 14.16, 22.75 (q, $J=0.6$ Hz), 26.96, 28.62, 29.05, 29.27, 29.92, 31.91, 60.84, 121.65 (q, $J=6.1$ Hz), 123.42 (q, $J=274.6$ Hz), 146.44 (q, $J=28.7$ Hz), 164.45; ^{19}F -NMR δ 92.67 (d, $J=1.3$ Hz). **(Z)-isomer:** ^1H NMR δ 0.88-1.58 (18 H, m), 2.26 (2 H, dt, $J=1.5, 7.7$ Hz), 4.24 (2 H, q, $J=7.1$ Hz), 6.03 (1 H, t, $J=1.3$ Hz); ^{13}C NMR δ 13.91, 14.10, 22.68, 27.48, 29.02, 29.16, 29.26, 29.42, 31.84, 61.36, 122.48 (q, $J=275.4$ Hz), 124.39 (q, $J=3.6$ Hz), 138.92 (q, $J=30.4$ Hz), 164.76; ^{19}F NMR δ 98.49 (d, $J=6.9$ Hz).

Ethyl 4,4,4-trifluoro-3-phenyl-2-butenolate (4c)¹

The desired product was obtained as an inseparable mixture of $E/Z=83/17$ in 87% yield. IR (neat) ν 3064, 2986, 2940, 2907, 1735, 1654, 1577, 1498, 1446, 1364, 1284, 1177, 1132, 1028, 984, 940, 909, 847, 764, 698, 658 cm^{-1} ; Anal. Calcd for $\text{C}_{12}\text{H}_{11}\text{F}_3\text{O}_2$: C, 59.02; H, 4.54. Found C, 58.61; H, 4.60. **(E)-isomer:** ^1H NMR δ 1.06 (3 H, t, $J=7.1$ Hz), 4.04 (2 H, q, $J=7.1$ Hz), 6.61 (1 H, q, $J=1.4$ Hz), 7.28-7.46 (5 H, aromatic); ^{13}C NMR δ 13.70, 61.07, 122.54 (q, $J=274.2$ Hz), 124.58 (q, $J=5.3$ Hz), 128.10, 128.57, 129.20, 131.01, 142.16 (q, $J=30.7$ Hz), 163.94; ^{19}F NMR δ 94.137(s). **(Z)-isomer:** ^1H NMR δ 1.36 (3 H, t, $J=7.1$ Hz), 4.31 (2 H, q, $J=7.1$ Hz), 6.34 (1 H, s), 7.28-7.46 (5 H, aromatic); ^{13}C NMR δ 13.94, 61.68, 122.15 (q, $J=275.1$ Hz), 127.38 (q, $J=3.5$ Hz), 127.55 (q, $J=0.9$ Hz), 127.99, 128.45, 129.34, 137.56 (q, $J=31.8$ Hz), 164.45; ^{19}F NMR δ 101.60 (s).

Typical procedure for DIBAL reduction of 4a-c

To a three-necked flask equipped with a pressure equalizing dropping funnel under an argon atmosphere was added a solution of **4** (10 mmol) in CH_2Cl_2 (20 mL). To this solution at -78°C was added 24 mL of DIBAL (24 mmol; 1 mol/L hexane solution) dropwise at that temperature and then the whole mixture was stirred for 1 h. The solution was allowed to warm to 0°C and stirred further 30 min where 3 N HCl aq. was added. After separation of the two layers, the aqueous solution was washed with CH_2Cl_2 twice and the combined organic layer was washed with brine, dried (MgSO_4) and concentrated under vacuum. The resulting crude product was purified by silica gel column chromatography.

5-Phenyl-3-(trifluoromethyl)-2-penten-1-ol (5a)

The desired product was obtained as an inseparable mixture of $E/Z=84/16$ in 99% yield. IR (neat) ν 3381, 3062, 3023, 2936, 2875, 1719, 1609, 1492, 1453, 1328, 1162, 1113, 1008, 750, 695 cm^{-1} ; Anal. Calcd for $\text{C}_{12}\text{H}_{13}\text{F}_3\text{O}$: C, 62.60; H, 5.69. Found C, 62.44; H, 5.74. **(E)-Isomer:** ^1H NMR δ 2.52 (2 H, t, $J=7.3$ Hz), 2.79 (2 H, t, $J=7.6$), 3.82 (2 H, m), 6.23 (1 H, qt, $J=1.7, 6.7$ Hz), 7.16-7.35 (5 H, aromatic); ^{13}C NMR δ 27.97 (q, $J=0.9$ Hz), 34.67, 57.92, 124.07 (q, $J=273.2$ Hz), 126.26, 128.35, 128.68, 129.07 (q, $J=28.06$ Hz), 133.80 (q, $J=5.9$ Hz), 140.28; ^{19}F NMR δ 94.75 (q, $J=2.0$ Hz). **(Z)-Isomer:** ^1H NMR δ 2.49-2.52 (2 H, m), 2.79 (2 H, t, $J=8.0$ Hz), 4.37 (2 H, m), 5.80 (1 H, t, $J=6.0$ Hz), 7.17-7.33 (5 H, aromatic); ^{13}C NMR δ 33.74 (q, $J=2.1$ Hz), 34.65, 58.66 (q, $J=3.0$ Hz), 124.02 (q, $J=275.6$ Hz), 126.09, 128.26, 128.32, 128.95 (q, $J=29.1$ Hz), 136.90 (q, $J=3.3$ Hz), 140.36; ^{19}F NMR δ 101.12 (t, $J=2.6$ Hz).

3-(Trifluoromethyl)-2-undecen-1-ol (5b)

The desired product was obtained as an inseparable mixture of $E/Z=81/19$ in 99% yield. IR (neat) ν 3328, 2927, 2857, 1685, 1467, 1329, 1224, 1168, 1119, 1030, 973, 877, 829, 722 cm^{-1} ; Anal. Calcd for $\text{C}_{12}\text{H}_{21}\text{F}_3\text{O}$: C, 60.48; H, 8.88. Found C, 60.55; H, 8.80. **(E)-isomer:** ^1H NMR δ 0.86-0.90 (3 H, m), 1.27 (12 H, bs), 2.15-2.20 (2 H, m), 4.32 (2 H, m), 6.24 (1 H, qt, $J=1.7, 6.2$ Hz); ^{13}C NMR δ 14.07, 22.68, 26.13, 28.35, 29.25, 29.29, 29.63, 31.88, 58.10, 123.98 (q, $J=273.1$ Hz), 131.22 (q,

$J=28.3$ Hz), 132.35 (q, $J=6.0$ Hz); ^{19}F NMR δ 94.00 (q, $J=1.7$ Hz). (**Z**)-**isomer**: ^1H NMR δ 0.87-0.90 (3 H, m), 1.29 (12 H, bs), 2.15-2.19 (2 H, m), 4.39-4.40 (2 H, m), 5.86 (1 H, t, $J=6.0$ Hz); ^{13}C NMR δ 14.11, 22.70, 28.23, 29.12, 29.23, 29.33, 31.78 (q, $J=2.2$ Hz), 31.87, 59.42 (q, $J=3.1$ Hz), 124.04 (q, $J=275.5$ Hz), 130.29 (q, $J=28.8$ Hz), 135.63 (q, $J=3.3$ Hz); ^{19}F NMR δ 100.95 (t, $J=2.8$ Hz).

4,4,4-Trifluoro-3-phenyl-2-buten-1-ol (**5c**)

The desired product was obtained as an inseparable mixture of $E/Z=83/17$ in 92% yield. IR (neat) ν 3330, 2938, 2866, 1653, 1576, 1363, 1348, 1295, 1172, 1120, 1028, 981, 931, 907, 771, 702, 668 cm^{-1} ; Anal. Calcd for $\text{C}_{10}\text{H}_9\text{F}_3\text{O}$: C, 59.41; H, 4.49. Found C, 59.46; H, 4.85. (**E**)-**isomer**: ^1H NMR δ 4.16 (2 H, m), 6.56 (1 H, qt, $J=1.6, 6.4$ Hz), 7.24-7.41 (5 H, aromatic); ^{13}C NMR δ 58.86, 122.97 (q, $J=272.7$ Hz), 128.41, 128.84, 129.12, 131.14 (q, $J=0.6$ Hz), 132.17 (q, $J=30.1$ Hz), 134.54 (q, $J=5.4$ Hz); ^{19}F NMR δ 95.54 (q, $J=2.0$ Hz). (**Z**)-**isomer**: ^1H NMR δ 4.59 (2 H, m), 6.21 (1 H, dt, $J=0.5, 5.7$ Hz), 7.24-7.41 (5 H, aromatic); ^{13}C NMR δ 59.32 (q, $J=3.7$ Hz), 123.45 (q, $J=275.1$ Hz), 127.73 (q, $J=0.9$ Hz), 128.23, 128.33, 130.99 (q, $J=30.9$ Hz), 135.02 (q, $J=2.0$ Hz), 140.29 (q, $J=2.9$ Hz); ^{19}F NMR δ 103.61 (t, $J=3.1$ Hz).

General procedure for the preparation of allylic acetate **6**

Allylic alcohol **5** (35 mmol) in CH_2Cl_2 (70 mL) was placed in a three-necked flask with stir bar under an argon atmosphere where at 0 °C was added 3.0 mL of acetyl chloride (42 mmol) followed by addition of 3.4 mL of pyridine (42 mmol). The reaction mixture was allowed to warm to room temperature and stirred for 30 min. The solution was quenched with water and after separation of the two layers, the aqueous solution was washed with CH_2Cl_2 twice and the combined organic layer was washed with brine, dried (MgSO_4) and concentrated under vacuum. The resulting mixture was purified by silica gel column chromatography.

5-Phenyl-3-(trifluoromethyl)-2-pentenyl acetate (**6a**)

The desired product was obtained as an inseparable mixture of $E/Z=84/16$ in quantitative yield. IR (neat) ν 3029, 2942, 1745, 1603, 1495, 1228, 1166, 1116, 1024, 905, 826, 748, 699 cm^{-1} ; Anal. Calcd for $\text{C}_{14}\text{H}_{15}\text{F}_3\text{O}_2$: C, 61.76; H, 5.55. Found C, 61.48; H, 5.86. (**E**)-**Isomer**: ^1H NMR δ 2.04 (3 H, s), 2.54 (2 H, t, $J=7.8$ Hz), 2.79 (2 H, t, $J=7.8$ Hz), 4.29 (2 H, m), 6.18 (1 H, qt, $J=1.6, 6.5$ Hz), 7.16-7.32 (5 H, aromatic); ^{13}C NMR δ 20.64, 28.29 (q, $J=0.9$ Hz), 34.70, 59.26, 123.85 (q, $J=273.4$ Hz), 126.25, 128.42, 128.49, 129.23 (q, $J=6.1$ Hz), 131.36 (q, $J=28.5$ Hz), 140.01, 170.15; ^{19}F NMR δ 94.39 (q, $J=2.3$ Hz). (**Z**)-**Isomer**: ^1H NMR δ 2.07 (3 H, s), 2.48-2.52 (2 H, m), 2.79 (2 H, t, $J=8.1$ Hz), 4.78-4.81 (2 H, m), 5.72 (1 H, t, $J=6.1$ Hz), 7.16-7.31 (5 H, aromatic); ^{13}C -NMR δ 20.70, 33.76, 34.54, 60.41 (q, $J=3.3$ Hz), 123.73 (q, $J=275.5$ Hz), 126.10, 128.27, 128.30, 128.95 (q, $J=29.1$ Hz), 131.69 (q, $J=3.2$ Hz), 140.12, 170.22; ^{19}F NMR δ 100.71 (t, $J=2.7$ Hz).

4,4,4-Trifluoro-3-phenyl-2-propenyl acetate (**6c**)

The desired product was obtained as an inseparable mixture of $E/Z=83/17$ in 87% yield. IR (neat) ν 3062, 3032, 2943, 2858, 1747, 1705, 1577, 1543, 1496, 1442, 1369, 1350, 1296, 1226, 1172, 1122, 1041, 975, 937, 914, 829, 771, 702, 671 cm^{-1} . (**E**)-**Isomer**: ^1H NMR δ 2.05 (3 H, s), 4.55 (2 H, m), 6.49 (1 H, qt, $J=1.6, 6.4$ Hz), 7.24-7.44 (5 H, aromatic); ^{13}C NMR δ 20.56, 60.43, 122.58 (q, $J=272.9$ Hz), 127.65 (q, $J=0.9$ Hz), 128.37, 128.88, 128.94, 129.95 (q, $J=5.6$ Hz), 134.01 (q, $J=30.5$ Hz), 170.12; ^{19}F NMR δ 95.22 (q, $J=2.0$ Hz). (**Z**)-**Isomer**: ^1H NMR δ 2.11 (3 H, s), 5.00 (2 H, m), 6.09 (1 H, t, $J=5.6$ Hz), 7.24-7.44 (5 H, aromatic); ^{13}C NMR δ 20.64, 60.86 (q, $J=4.2$ Hz), 123.17 (q, $J=275.1$ Hz), 128.15, 128.44, 130.60, 135.06 (q, $J=2.9$ Hz), 170.19; ^{19}F NMR δ 103.17 (t, $J=2.8$ Hz).

General preparation of the primary allylic phosphate **7a-c**

Allylic alcohol **5** (10 mmol) in CH_2Cl_2 (20 mL) was placed in a three-necked flask with stir bar under an argon atmosphere where at 0 °C was added 37 mg of DMAP (0.3 mmol), 1.7 mL of diethyl chlorophosphate (12 mmol) followed by addition of 1.7 mL of triethylamine (12 mmol). The reaction mixture was allowed to warm to room temperature and stirred overnight. The solution was

quenched with water and after separation of the two layers, the aqueous solution was washed with CH_2Cl_2 twice and the combined organic layer was washed with brine, dried (MgSO_4) and concentrated under vacuum. The resulting mixture was purified by silica gel column chromatography.

Diethyl 5-phenyl-3-(trifluoromethyl)-2-pentenyl phosphate (7a)

The desired product was obtained as an inseparable mixture of *E/Z*=84/16 in 92% yield. IR (neat) ν 2986, 1869, 1844, 1700, 1675, 1457, 1437, 1388, 1363, 1272, 1166, 1117, 1033, 828, 747, 701, 668 cm^{-1} ; Anal. Calcd for $\text{C}_{16}\text{H}_{22}\text{F}_3\text{O}_4\text{P}$: C, 52.46; H, 6.05. Found C, 52.28; H, 6.06. (*E*)-isomer: ^1H NMR δ 1.31 (3 H, t, $J=7.0$ Hz), 1.32 (3 H, t, $J=7.0$ Hz), 2.52 (2 H, t, $J=7.7$ Hz), 2.78 (2 H, t, $J=7.7$ Hz), 4.06 (2 H, q, $J=7.1$ Hz), 4.09 (2 H, q, $J=7.1$ Hz), 4.20 (2 H, m), 6.24 (1 H, qt, $J=1.6, 6.4$ Hz), 7.14-7.33 (5 H, aromatic); ^{13}C NMR δ 16.04, 16.13, 28.35, 34.67, 61.84 (d, $J=5.2$ Hz), 63.87, 63.94, 123.76 (q, $J=273.3$ Hz), 126.32, 128.45, 128.54, 129.93 (qd, $J=6.2, 7.2$ Hz), 131.14 (q, $J=28.7$ Hz), 139.87; ^{19}F NMR δ 94.23 (q, $J=2.0$ Hz). (*Z*)-isomer: ^1H NMR δ 1.34 (3 H, $J=7.1$ Hz), 1.35 (3 H, $J=7.0$ Hz), 2.47-2.54 (2 H, m), 2.80 (2 H, t, $J=8.0$ Hz), 4.10 (2 H, q, $J=7.1$ Hz), 4.13 (2 H, q, $J=7.1$ Hz), 4.72-4.80 (2H, m), 5.81 (1 H, t, $J=5.8$ Hz), 7.15-7.33 (5 H, aromatic); ^{13}C NMR δ 15.79, 15.88, 33.29 (q, $J=2.0$ Hz), 34.18, 62.81 (qd, $J=3.5, 5.0$ Hz), 63.59, 63.68, 123.42 (q, $J=275.3$ Hz), 125.87, 127.97, 128.05, 130.18 (q, $J=29.5$ Hz), 132.18 (qd, $J=3.2, 8.1$ Hz), 139.72; ^{19}F NMR δ 100.55 (t, $J=2.6$ Hz).

Diethyl 3-(trifluoromethyl)-2-undecenyl phosphate (7b)

The desired product was obtained as an inseparable mixture of *E/Z*=81/19 in 92% yield. IR (neat) ν 2978, 2858, 1639, 1678, 1458, 1446, 1392, 1354, 1265, 1173, 1119, 1026, 979, 891, 829, 748, 725 cm^{-1} . Anal. Calcd for $\text{C}_{16}\text{H}_{30}\text{F}_3\text{O}_4\text{P}$: C, 51.33; H, 8.08. Found C, 50.86; H, 8.51. (*E*)-isomer: ^1H -NMR δ 0.86-0.91 (3 H, m), 1.27 (12 H, bs), 1.34 (3 H, t, $J=7.0$ Hz), 1.35 (3 H, t, $J=7.0$ Hz), 2.17-2.23 (2 H, m), 4.12 (2 H, q, $J=7.1$ Hz), 4.14 (2 H, q, $J=7.1$ Hz), 4.64-4.71 (2 H, m), 6.23 (1 H, qt, $J=1.7, 6.3$ Hz); ^{13}C NMR δ 14.07, 16.04, 16.13, 22.61, 26.18 (q, $J=1.0$ Hz), 28.99, 29.13, 29.19, 31.76, 31.78, 62.30 (d, $J=4.9$ Hz), 63.95, 64.03, 123.60 (q, $J=273.2$ Hz), 128.24 (qd, $J=6.3, 7.4$ Hz), 133.20 (dq, $J=1.1, 28.6$ Hz); ^{19}F NMR δ 93.83 (q, $J=2.0$ Hz). (*Z*)-isomer: ^1H NMR δ 4.77 (2H, bs), 5.84 (1H, t, $J=5.6$ Hz); ^{13}C NMR δ 14.09, 16.07, 16.16, 22.66, 28.04, 29.02, 29.18, 29.27, 31.58 (q, $J=1.8$ Hz), 31.82, 63.26, 63.89, 63.93, 123.71 (q, $J=275.5$ Hz), 131.21 (qd, $J=3.2, 8.9$ Hz), 131.65 (q, $J=28.9$ Hz); ^{19}F NMR δ 100.37 (t, $J=2.6$ Hz).

Diethyl 4,4,4-trifluoro-3-phenyl-2-butenyl phosphate (7c)

The desired product was obtained as an inseparable mixture of *E/Z*=83/17 in 92% yield. IR (neat) ν 3059, 2985, 2935, 2912, 2873, 1654, 1639, 1493, 1446, 1392, 1354, 1265, 1173, 1126, 1026, 987, 914, 833, 771, 744, 702, 671 cm^{-1} . Anal. Calcd for $\text{C}_{14}\text{H}_{19}\text{F}_3\text{O}_4\text{P}$: C, 49.71; 5.36. Found C, 49.75; H, 5.26. (*E*)-isomer: ^1H NMR δ 1.31 (3 H, dq, $J=7.1$ Hz), 1.32 (3 H, dq, $J=7.1$ Hz), 4.08 (2 H, q, $J=7.1$ Hz), 4.11 (2 H, q, $J=7.1$ Hz), 4.52 (2 H, m), 6.56 (1 H, qt, $J=1.6, 6.4$ Hz), 7.23-7.44 (5 H, aromatic); ^{13}C NMR δ 15.74, 15.83, 62.88 (d, $J=4.9$ Hz), 63.69, 63.77, 122.40 (q, $J=273.0$ Hz), 128.31, 128.74, 128.91, 129.14, 130.39 (qd, $J=5.6, 8.2$ Hz), 133.74 (q, $J=30.5$ Hz); ^{19}F NMR δ 95.13 (q, $J=2.0$ Hz). (*Z*)-isomer: ^1H NMR δ 1.35 (6 H, dq, $J=1.10, 7.14$ Hz), 4.14 (2 H, q, $J=7.0$ Hz), 4.17 (2 H, q, $J=7.2$ Hz), 4.96 (2 H, m), 6.20 (1 H, t, $J=5.4$ Hz); ^{13}C NMR δ 16.06, 16.16, 63.57, 64.01, 64.09, 123.21 (q, $J=275.3$ Hz), 127.73 (q, $J=0.8$ Hz), 128.32, 128.66, 129.04, 132.188 (dq, $J=1.1, 32.1$ Hz), 135.67 (qd, $J=2.4, 8.0$ Hz); ^{19}F NMR δ 103.11 (t, $J=2.8$ Hz).

Typical procedure for CuCN catalyzed Grignard reaction of allylic derivatives

To a flask, containing CuCN (9 mg, 0.1 mmol) in Et_2O (1.2 mL) was added 0.063 mL of TMSCl (0.5 mmol) dropwise and stirred at room temperature for several minutes under an argon atmosphere. To the resulting mixture were added allylic acetates **6**, **14** or the corresponding phosphate **7** (0.5 mmol) in ether (1.2 mL). 0.75 mL of Grignard reagent (0.75 mmol; 1.0 mol/L Et_2O solution) at 0 °C was added dropwise and the reaction was usually completed within 5 minutes. The solution was quenched with a saturated NH_4Cl aq. at 0 °C, followed by addition of 10% NH_3 aq. and stirred at room temperature until the aqueous solution turned blue. After

separation of two layers, the aqueous solution was washed with ether twice. The combined organic layer was washed with brine and dried MgSO_4 and concentrated under vacuum. The resulting crude product was purified by silica gel column chromatography.

3-Methyl-5-phenyl-3-(trifluoromethyl)-1-pentene (8aa)

The desired products were obtained as an inseparable mixture of **8aa:9aa:10a**=86:4:10. ^1H NMR δ 1.30 (3 H, s), 1.82-2.00 (2 H, m), 2.43-2.62 (2 H, m), 5.31 (1 H, d, $J=17.6$ Hz), 5.39 (1 H, d, $J=11.0$ Hz), 5.89 (1 H, dd, $J=10.9, 17.4$ Hz), 7.16-7.32 (5 H, *aromatic*); ^{13}C NMR δ 16.13 (q, $J=2.4$ Hz), 29.86 (q, $J=1.0$ Hz), 36.08 (q, $J=1.7$ Hz), 46.36 (q, $J=24.1$ Hz), 117.82, 125.85, 127.97 (q, $J=282.6$ Hz), 128.08, 128.28, 136.15 (q, $J=1.9$ Hz), 141.48; ^{19}F NMR δ 85.23 (s). (*E*)-**9aa**: ^1H NMR δ 6.10 (1 H, t, $J=7.2$ Hz); ^{13}C NMR δ 25.24 (q, $J=1.7$ Hz); ^{19}F NMR δ 95.03 (s).

3-Ethyl-5-phenyl-3-(trifluoromethyl)-1-pentene (8ab)

^1H NMR δ 0.96 (3 H, qt, $J=1.0, 7.6$ Hz), 1.68-1.76 (1 H, m), 1.81-1.89 (2 H, m), 1.95-2.01 (1 H, m), 2.55-2.66 (2 H, m), 5.28 (1 H, d, $J=17.8$ Hz), 5.39 (1 H, d, $J=11.0$ Hz), 5.80 (1H, dd, $J=11.2, 20.3$ Hz), 7.18-7.32 (5 H, *aromatic*); ^{13}C NMR δ 7.94 (q, $J=1.3$ Hz), 23.96 (q, $J=1.9$ Hz), 29.96 (q, $J=1.5$ Hz), 33.05 (q, $J=1.6$ Hz), 48.96 (q, $J=22.6$ Hz), 117.78, 128.12, 128.24 (q, $J=284.2$ Hz), 128.35, 135.87 (q, $J=2.4$ Hz), 141.87; ^{19}F NMR δ 89.95 (s). IR (neat) ν 3089, 3066, 3028, 2974, 2947, 2889, 1944, 1870, 1801, 1716, 1639, 1604, 1496, 1458, 1419, 1384, 1319, 1249, 1165, 1138, 1118, 1072, 999, 929, 829, 756, 698 cm^{-1} . Anal. Calcd for $\text{C}_{14}\text{H}_{17}\text{F}_3$: C, 69.40; H, 7.07. Found C, 69.31, H, 7.22.

4-Methyl-3-(2-phenylethyl)-3-(trifluoromethyl)-1-pentene (8ac)

The desired products were obtained as an inseparable mixture of **8ac:9ac:10a**=39:44:17. ^1H NMR δ 1.00 (6 H, m), 1.83-1.95 (2 H, m), 2.15 (1 H, sept, $J=6.9$ Hz), 2.61-2.77 (2H, m), 5.27 (1 H, d, $J=17.9$ Hz), 5.40 (1 H, d, $J=11.5$ Hz), 5.85 (1 H, dd, $J=11.3, 17.6$ Hz), 7.16-7.33 (5 H, *aromatic*); ^{13}C NMR δ 51.84 (q, $J=21.5$ Hz), 134.44 (q, $J=2.7$ Hz), 141.07; ^{19}F NMR δ 95.66 (s). (*E*)-**9ac**: ^1H NMR δ 0.88 (6 H, d, $J=6.6$ Hz), 1.62 (1 H, sept, $J=6.6$ Hz), 6.14 (1 H, qt, $J=1.8, 7.4$ Hz); ^{13}C NMR δ 134.07 (q, $J=6.1$ Hz); ^{19}F NMR δ 95.20 (q, $J=2.2$ Hz). (*Z*)-**9ac**: ^1H NMR δ 0.83 (6 H, d, $J=6.6$ Hz), 5.59 (1 H, t, $J=7.6$ Hz); ^{19}F NMR δ 102.525 (t, $J=2.6$ Hz). The ratio of (*E*)-**9ac**/**(Z)**-**9ac**=90/10. **10a**: ^1H NMR δ 5.15 (1 H, d, $J=11.0$ Hz), 5.26 (1 H, d, $J=17.6$ Hz), 6.40 (1 H, tdd, $J=1.2, 11.3, 17.6$ Hz); ^{13}C NMR δ 34.16 (dd, $J=2.0, 2.9$ Hz), 113.12 (dd, $J=4.6, 10.0$ Hz), 127.57 (dd, $J=1.1, 2.6$ Hz), ^{19}F NMR δ 70.93 (1 F, d, $J=31.3$ Hz), 71.04 (1 F, d, $J=30.8$). The following ^{13}C NMR peaks can not be properly assigned: δ 17.66 (q, $J=1.7$ Hz), 17.97 (q, $J=1.9$ Hz), 22.14, 22.30, 25.23, 25.25, 27.95 (q, $J=0.9$ Hz), 28.07 (q, $J=1.1$ Hz), 28.50 (q, $J=0.9$ Hz), 30.17 (q, $J=1.7$ Hz), 30.44 (q, $J=1.3$ Hz), 32.14 (q, $J=1.9$ Hz), 35.01, 35.22, 36.04, 117.59 (q, $J=0.9$ Hz), 122.77, 125.83, 125.93, 125.96, 126.39, 126.51, 1228.11, 128.16, 128.19, 128.24, 128.25, 128.34, 128.89, 130.30, 140.96.

5-Methyl-3-(2-phenylethyl)-3-(trifluoromethyl)-1-hexene (8ad)

The desired products were obtained as an inseparable mixture of **8ad:9ad:10a**=86:8:6.

^1H NMR δ 0.96 (3 H, d $J=6.6$ Hz), 0.99 (3 H, d, $J=6.6$ Hz), 1.43-2.09 (5 H, m), 2.57-2.78 (2 H, m), 5.29 (1 H, d, $J=17.6$ Hz), 5.35 (1 H, d, $J=11.3$ Hz), 5.86 (1 H, dd, $J=11.3, 17.9$ Hz), 7.18-7.33 (5 H, *aromatic*); ^{13}C NMR δ 22.33, 23.69, 24.90, 30.29 (q, $J=1.7$ Hz), 34.21 (q, $J=1.4$ Hz), 40.39, 49.26 (q, $J=22.6$ Hz), 117.32, 125.87, 128.10, 128.12 (q, $J=284.4$ Hz), 128.35, 136.78 (q, $J=2.4$ Hz), 140.90; ^{19}F NMR δ 90.09 (s). (*E*)-**9ad**: ^1H NMR δ 0.86 (3 H, d, $J=6.6$ Hz), 6.10 (1 H, qt, $J=1.4, 7.3$ Hz); ^{13}C NMR 37.65 (q, $J=1.2$ Hz), 135.47 (q, $J=6.1$ Hz); ^{19}F NMR 95.13 (q, $J=1.7$ Hz); (*Z*)-**9ad**: 102.23 (t, $J=2.6$ Hz). The ratio of (*E*)-**9ad**/**(Z)**-**9ad**=89/11.

5-Phenyl-3-(2-phenylethyl)-3-(trifluoromethyl)-1-pentene (8af)

The desired product was obtained as an inseparable mixture of **8af:9af:10a**=97:3:<1.

IR (neat) ν 3062, 3028, 2927, 2854, 1712, 1654, 1639, 1604, 1543, 1319, 1249, 1228, 1153, 1126, 1029, 999, 929, 906, 840, 744, 693 cm^{-1} . Anal. Calcd. For $\text{C}_{20}\text{H}_{21}\text{F}_3$: C, 75.45, H, 6.65. Found C, 75.36, H, 7.01. ^1H NMR δ 1.89-1.99 (2 H, m), 2.03-2.14 (2 H, m), 2.59-2.75 (4 H, m), 5.35 (1 H, d, $J=17.6$ Hz), 5.45 (1 H, d, $J=11.0$ Hz), 5.89 (1 H, dd, $J=17.9, 11.1$ Hz), 7.15-7.34 (10H, *aromatic*); ^{13}C NMR δ 30.50 (q, $J=1.2$ Hz), 34.15, 49.46 (q, $J=22.9$ Hz), 118.63, 128.55 (q, $J=284.1$ Hz), 128.65, 128.92, 136.18 (q, $J=2.4$ Hz), 142.10; ^{19}F NMR δ 90.03 (s). (*E*)-**9af**: ^{19}F NMR δ 95.07 (s).

3-Methyl-3-(trifluoromethyl)-1-undecene (8ba)

The desired products were obtained as an inseparable mixture of **8ba:9ba:10b**=81:8:11. ¹H NMR δ 0.86-0.90 (3 H, m), 1.19 (3 H, s), 1.26 (12 H, bs), 1.51-1.59 (2 H, m), 5.21 (1 H, d, *J*=17.6 Hz), 5.30 (1 H, d, *J*=11.0 Hz), 5.79 (1 H, dd, *J*=11.0, 17.6 Hz); ¹³C NMR δ 14.20, 14.22, 16.02 (q, *J*=2.2 Hz), 22.78, 23.40 (q, *J*=0.9 Hz), 29.56, 30.19, 31.97, 33.96 (q, *J*=1.7 Hz), 46.33 (q, *J*=23.7 Hz), 117.39, 128.21 (q, *J*=282.5 Hz), 136.68 (q, *J*=2.0 Hz); ¹⁹F NMR δ 85.07 (s). (*E*)-**9ba**: ¹H NMR δ 1.03 (3 H, t, *J*=7.4 Hz), 6.06 (1 H, t, *J*=7.5 Hz); ¹³C NMR δ 23.12 (q, *J*=1.4 Hz), ¹⁹F NMR δ 94.67 (q, *J*=1.7 Hz). (*Z*)-**9ba**: ¹⁹F NMR δ 101.90 (s). The ratio of (*E*)-**9ba**/**(Z)**-**9ba**=83/17.

3-Ethyl-3-(trifluoromethyl)-1-undecene (8bb)

¹H NMR δ 0.86-0.94 (6 H, m), 1.27 (12 H, bs), 1.40-1.81 (4 H, m), 5.20 (1H, d, *J*=17.9 Hz), 5.32 (1H, d, *J*=11.0 Hz), 5.723 (1H, dd, *J*=11.0, 17.6 Hz); ¹³C NMR δ 7.99 (q, *J*=1.4 Hz), 14.15, 22.82, 23.36 (q, *J*=1.3 Hz), 23.90 (q, *J*=1.9 Hz), 29.48, 29.61, 30.52, 30.79 (q, *J*=1.6 Hz), 32.03, 48.872 (q, *J*=22.5 Hz), 117.28, 128.41 (q, *J*=284.2 Hz), 136.47 (q, *J*=2.5 Hz); ¹⁹F NMR δ 89.79 (s). IR (neat) ν 3086, 3063, 3028, 2974, 2947, 2874, 2731, 1736, 1605, 1496, 1458, 1388, 1311, 1254, 1219, 1169, 1141, 1118, 1072, 1030, 1003, 910, 783, 740, 698, 671 cm⁻¹. Anal. Calcd for C₁₄H₂₅F₃: C, 67.17; H, 10.07. Found C, 66.90; H, 9.94.

3-Isopropyl-3-(trifluoromethyl)-1-undecene (8bc)

The desired products were obtained as an inseparable mixture of **8bc:9bc:10b**=59:35:6.

¹H NMR δ 0.86-1.75, 1.97-2.17 (24 H, m), 5.20 (1 H, d, *J*=17.9 Hz), 5.33 (1 H, d, *J*=11.3 Hz), 5.79 (1 H, dd, *J*=11.3, 17.9 Hz); ¹³C NMR δ 14.21, 17.77, 18.10 (q, *J*=1.7 Hz), 22.84, 23.56 (q, *J*=1.4 Hz), 25.97 (q, *J*=0.9 Hz), 29.51, 29.62, 30.36 (q, *J*=1.5 Hz), 30.77, 32.05, 51.74 (q, *J*=21.2 Hz), 117.24, 128.61 (q, *J*=286.6 Hz), 135.06 (q, *J*=2.7 Hz). ¹⁹F NMR 95.49 (s). (*E*)-**9bc**: ¹H NMR δ 6.09 (1 H, qt, *J*=1.9, 7.5 Hz), 6.39 (1 H, tdd, *J*=1.5, 11.3, 17.6 Hz); ¹³C NMR δ 22.45, 28.41 (q, *J*=1.1 Hz), 29.40, 29.46, 36.35, 130.14 (q, *J*=27.5 Hz), 132.94 (q, *J*=6.1 Hz); ¹⁹F NMR δ 94.87 (q, *J*=2.2 Hz). (*Z*)-**9bc**: ¹⁹F NMR δ 102.14 (s). The ratio of (*E*)-**9bc**/**(Z)**-**9bc**=83/17. **10b**: ¹H NMR δ 5.10 (1 H, d, *J*=11.0 Hz), 5.17 (1 H, d, *J*=17.7 Hz); ¹³C NMR δ 28.15 (dd, *J*=2.0 Hz), 113.01 (dd, *J*=10.3, 4.2 Hz); ¹⁹F NMR δ 70.21 (1 F, d, *J*=33.6 Hz), 70.41 (1 F, d, *J*=32.8 Hz).

3-Isobutyl-3-(trifluoromethyl)-1-undecene (8bd)

The desired products were obtained as an inseparable mixture of **8bd:9bd:10b**=79:20:1.

¹H NMR δ 0.85-1.76, 2.06-2.18 (26 H, m), 5.23 (1 H, d, *J*=17.9 Hz), 5.29 (1 H, d, *J*=11.3 Hz), 5.78 (1 H, dd, *J*=11.3, 17.7 Hz); ¹³C NMR δ 14.23, 22.86, 23.78, 23.81 (q, *J*=1.4 Hz), 25.02, 25.11, 25.39, 29.50, 29.64, 30.64, 32.06, 40.45, 49.25 (q, *J*=22.4 Hz), 116.93, 128.33 (q, *J*=284.4 Hz), 137.43 (q, *J*=2.4 Hz); ¹⁹F NMR δ 89.94 (s). (*E*)-**9bd**: ¹H NMR δ 6.06 (1 H, tq, *J*=1.4, 7.0 Hz); ¹³C NMR δ 22.50, 25.91, 27.82, 27.88, 28.95, 29.22, 29.43, 29.48, 29.56, 29.85, 32.13 (q, *J*=1.2 Hz), 38.09, 134.27; ¹⁹F NMR δ 94.79 (q, *J*=1.7 Hz). (*Z*)-**9bd** ¹⁹F NMR δ 101.97 (t, *J*=2.5 Hz). The ratio of (*E*)-**9bd**/**(Z)**-**9bd**=87/13.

3-(2-Phenylethyl)-3-(trifluoromethyl)-1-undecene (8bf)

The desired products were obtained as an inseparable mixture of **8bf:9bf:10b**=97:3:<1. IR (neat) ν 3086, 3062, 2927, 2854, 1639, 1604, 1496, 1458, 1415, 1377, 1327, 1249, 1161, 1138, 1029, 999, 929, 740, 698 cm⁻¹. Anal. Calcd for C₂₀H₂₉F₃: C, 73.59; H, 8.95. Found: C, 73.14; H, 8.50. ¹H NMR δ 0.86-0.91 (3 H, m), 1.30 (12 H, bs), 1.59-2.04 (4 H, m), 2.52-2.66 (2 H, m), 5.27 (1 H, d, *J*=17.6 Hz), 5.37 (1 H, d, *J*=11.0 Hz), 5.81 (1 H, dd, *J*=11.1, 17.7 Hz), 7.17-7.33 (5 H, aromatic); ¹³C NMR δ 14.14, 22.74, 23.31 (q, *J*=1.2 Hz), 29.36, 29.48, 30.07 (q, *J*=1.4 Hz), 30.34, 31.37 (q, *J*=1.7 Hz), 31.91, 33.53, 48.82 (q, *J*=22.8 Hz), 117.56, 125.86, 128.10, 128.18 (q, *J*=284.4 Hz), 128.34, 136.20 (q, *J*=2.4 Hz), 141.86; ¹⁹F NMR δ 89.86 (s). (*E*)-**9bf**: ¹⁹F NMR δ 94.72 (q, *J*=2.8 Hz).

3-Phenyl-3-(trifluoromethyl)-1-undecene (8ca)

The desired products were obtained as an inseparable mixture of **8ca:9ca:10b**=75:25:<1. IR (neat) ν 3032, 2954, 2927, 2854, 1774, 1720, 1639, 1496, 1465, 1450, 1377, 1303, 1246, 1149, 1122,

1064, 1033, 1002, 929, 906, 759, 698 cm⁻¹. Anal. Calcd for C₁₈H₂₅F₃: C, 72.45; H, 8.44: Found C, 71.96; H, 8.89. ¹H NMR δ 0.84-0.89 (3 H, m), 1.23 (12 H, bs), 1.94-2.19 (2 H, m), 5.31 (1 H, d, *J*=17.9 Hz), 5.49 (1 H, d, *J*=11.3 Hz), 6.03 (1 H, qdd, *J*=1.1, 11.9, 17.4 Hz), 7.21-7.45 (5 H, aromatic); ¹³C NMR δ 14.09, 22.65, 23.76 (q, *J*=1.1 Hz), 28.24, 29.26, 29.32, 30.16, 31.82, 54.74 (q, *J*=23.4 Hz), 118.15 (q, *J*=1.3 Hz), 127.20 (q, *J*=283.9 Hz), 127.39, 127.92, 128.75 (q, *J*=1.3 Hz), 129.54, 135.56 (q, *J*=1.7 Hz); ¹⁹F NMR δ 91.53 (s). (*E*)-**9ca**: ¹H NMR δ 6.414 (1 H, qt, *J*=1.8, 7.6 Hz); ¹³C NMR δ 22.68, 28.73 (q, *J*=1.2 Hz), 29.09, 29.43, 31.86, 32.99 (q, *J*=1.7 Hz), 121.61, 128.09, 128.14, 129.08, 132.33, 136.63 (q, *J*=5.5 Hz); ¹⁹F NMR δ 96.04 (q, *J*=2.2 Hz). (*Z*)-**9ca**: ¹⁹F NMR 104.60 (s). The ratio of (*E*)-**9ca**/*(Z)*-**9ca**=89/11.

5-Methyl-3-phenyl-3-(trifluoromethyl)-1-hexene (**8cb**)

The desired products were obtained as an inseparable mixture of **8cb**:**9cb**:**10c**=33:67:<1. IR (neat) ν 3062, 3028, 2958, 2931, 2870, 1662, 1496, 1465, 1450, 1381, 1369, 1319, 1300, 1249, 1168, 1149, 1118, 1049, 1002, 929, 906, 844, 759, 732, 702, 667 cm⁻¹. Anal. Calcd for C₁₄H₁₇F₃: C, 69.40; H, 7.07. Found: C, 69.46; H, 7.48. ¹H NMR δ 0.74 (3 H, d, *J*=6.9 Hz), 0.87 (3 H, *J*=6.9 Hz), 5.37 (1 H, d, *J*=18.8 Hz), 5.49 (1 H, d, *J*=11.3 Hz), 6.04 (1 H, qdd, *J*=1.2, 11.5, 17.9 Hz), 7.22-7.48 (5 H, aromatic); ¹³C NMR δ 24.01 (q, *J*=0.7 Hz), 26.77 (q, *J*=2.0 Hz), 37.81 (q, *J*=1.1 Hz), 55.06 (q, *J*=23.2 Hz), 135.99 (q, *J*=1.5 Hz); ¹⁹F NMR δ 92.03 (s). (*E*)-**9cb**: ¹H NMR δ 0.79 (6 H, d, *J*=6.6 Hz), 6.41 (1 H, qt, *J*=1.7, 7.6 Hz); ¹³C NMR δ 22.27, 24.68, 24.84, 26.20, 27.47, 117.94 (q, *J*=1.4 Hz), 127.24, 128.13, 129.49, 136.74 (q, *J*=5.4 Hz); ¹⁹F NMR δ 96.03 (q, *J*=2.0 Hz). (*Z*)-**9cb** 104.55 (t, *J*=2.8 Hz). The ratio of (*E*)-**9cb**/*(Z)*-**9cb**=85/15. The following ¹³C NMR peaks can not be properly assigned: ¹H NMR δ 1.23-1.31 (2 H, m), 1.34-1.53 (m), 1.58-1.75 (1 H, m), 1.94-2.14 (m); ¹³C NMR δ 22.34, 27.70, 41.67 (q, *J*=1.5 Hz), 127.43, 127.84, 128.74 (q, *J*=1.5 Hz),

4,4-Dimethyl-3-phenyl-3-(trifluoromethyl)-1-pentene (**8cc**)

The desired products were obtained as an inseparable mixture of **8cc**:**9cc**:**10c**=8:92:<1. IR (neat) ν 2958, 2904, 2870, 1654, 1473, 1365, 1323, 1296, 1276, 1238, 1172, 1118, 1076, 1014, 956, 767, 702 cm⁻¹. ¹H NMR δ 5.02 (1 H, d, *J*=10.7 Hz), 5.24 (1 H, d, *J*=17.6 Hz). (*E*)-**9cc**: ¹H NMR δ 0.88 (9 H, s), 1.89 (2 H, qd, *J*=2.3, 7.7 Hz), 6.51 (1 H, qt, *J*=1.7, 7.7 Hz), 7.19-7.41 (5 H, aromatic); ¹³C NMR δ 25.29, 27.48 (q, *J*=2.3 Hz), 29.25, 29.94, 41.79, 126.96 (q, *J*=271.1 Hz), 128.05, 128.09, 129.72, 131.98 (q, *J*=29.2 Hz), 133.73 (q, *J*=5.4 Hz), 139.12. ¹⁹F NMR δ 95.93 (q, *J*=2.2 Hz). (*Z*)-**9cc**: 0.99 (9 H, s), 2.44 (2 H, qd, *J*=2.5, 8.1 Hz), 6.09 (1 H, qt, *J*=1.0, 8.0 Hz); ¹³C NMR δ 25.23, 42.17 (q, *J*=1.4 Hz); ¹⁹F NMR δ 105.21 (t, *J*=2.8 Hz).

1,1,1-Trifluoro-1,3-diphenyl-2-butene (**9cd**)

The desired product was obtained as an inseparable mixture of *E/Z*=88/12 in 61% yield. IR (neat) ν 3062, 3028, 2924, 2854, 1662, 1600, 1492, 1454, 1377, 1307, 1273, 1168, 1114, 1076, 1029, 960, 929, 910, 871, 767, 736, 698, 667 cm⁻¹. (*E*)-**9cd**: ¹H NMR δ 3.34 (2 H, qd, *J*=2.2, 7.7 Hz), 6.59 (1 H, qt, *J*=1.7, 7.7 Hz), 7.10-7.61 (10 H, aromatic); ¹³C NMR δ 34.37, 123.20 (q, *J*=272.5 Hz), 126.36, 126.93, 127.02, 128.12, 128.32, 128.41, 128.49, 129.53, 134.50 (q, *J*=5.4 Hz), 136.60 (q, *J*=28.9 Hz); ¹⁹F NMR δ 95.86 (q, *J*=2.2 Hz). (*Z*)-**9cd**: ¹H NMR δ 3.79 (2 H, qd, *J*=2.3, 8.0 Hz), 6.17 (1 H, qt, *J*=0.9, 7.8 Hz); ¹³C NMR δ 35.02, 128.52, 128.55, 131.41; ¹⁹F NMR δ 105.03 (t, *J*=2.6 Hz).

3,5-Diphenyl-3-(trifluoromethyl)-1-pentene (**8ce**)

The desired products were obtained as an inseparable mixture of **8ce**:**9ce**:**10c**=68:32:<1. IR (neat) ν 3062, 3024, 2936, 2858, 1944, 1870, 1801, 1654, 1639, 1600, 1496, 1450, 1381, 1300, 1242, 1149, 1113, 1064, 1029, 937, 910, 840, 744, 698 cm⁻¹. ¹H NMR δ 1.63-1.77 (2 H, m), 2.30-2.72 (2H, m), 5.42 (1 H, d, *J*=17.9 Hz), 5.58 (1 H, d, *J*=11.3 Hz), 6.13 (1 H, qdd, *J*=1.1, 11.0, 17.9 Hz), 7.08-7.53 (10 H, aromatic); ¹³C NMR δ 30.28 (q, *J*=1.2 Hz), 35.16, 54.76 (q, *J*=23.7 Hz), 125.43, 125.88, 127.07 (q, *J*=284.0 Hz), 127.61, 128.01, 128.10, 128.32, 128.68 (q, *J*=1.3 Hz), 129.44, 135.20 (q, *J*=1.8 Hz), 142.30; ¹⁹F NMR δ 91.73 (s). (*E*)-**9ce**: ¹H NMR δ 2.00-2.10 (2 H, m), 6.43 (1 H, qt, *J*=1.7, 7.6 Hz); ¹³C NMR δ 27.76, 31.05, 35.78, 118.70 (q, *J*=1.3 Hz), 125.13, 125.66, 127.77, 128.03, 128.08, 128.14, 128.17, 128.18, 131.25 (q, *J*=29.5 Hz), 136.10 (q, *J*=5.5 Hz), 141.32, 141.47; ¹⁹F NMR δ 95.99 (q, *J*=2.2 Hz). (*Z*)-**9ce**: ¹H NMR δ 6.03 (1 H, t, *J*=7.7 Hz).

^{19}F NMR δ 104.53 (t, $J=2.6$ Hz). The ratio of (*E*)-**9ce**/(*Z*)-**9ce**=89/11.

Typical procedure of ozonolysis

The $\text{S}_{\text{N}}2'$ product **8** or **15** (0.5 mmol) dissolved in a solvent (**8**:1.0 mL in CH_2Cl_2 , **15**:1.0 mL in MeOH) was cooled to -78°C and then ozone gas was bubbled into the solution. After the solution was turned blue, argon gas was bubbled into the reaction mixture at that temperature. 0.055 mL of dimethyl sulfide (0.75 mmol) was added to and the mixture was allowed to warm to room temperature for 1 h. To this solution was added water and after separation of the two layers, the aqueous solution was washed with CH_2Cl_2 or ethyl acetate twice and the combined organic layer was washed with brine, dried (MgSO_4) and concentrated under vacuum. The resulting mixture was purified by silica gel column chromatography.

2-Ethyl-4-phenyl-2-(trifluoromethyl)butanal (**11aa=16**)

^1H NMR δ 0.98 (3 H, qt, $J=1.2$, 7.6 Hz), 1.93 (2 H, q, $J=7.6$ Hz), 1.99-2.15 (2 H, m), 2.51-2.69 (2 H, m), 7.18-7.33 (5 H, *aromatic*), 9.68 (1 H, q, $J=1.3$ Hz); ^{13}C NMR δ 7.95 (q, $J=1.2$ Hz), 18.41, 21.52 (q, $J=2.0$ Hz), 29.83 (q, $J=1.4$ Hz), 58.40 (q, $J=21.8$ Hz), 126.24, 126.75 (q, $J=284.7$ Hz), 128.12, 128.49, 140.87, 196.84 (q, $J=2.8$ Hz); ^{19}F NMR δ 93.83 (s). IR (neat) ν 3086, 3062, 3028, 2974, 2947, 2873, 2731, 1736, 1604, 1496, 1458, 1388, 1311, 1253, 1219, 1168, 1141, 1118, 1072, 1029, 1002, 910, 783, 740, 698, 671 cm^{-1} . $[\alpha]_{\text{D}}^{21}$ 13.2° (*c* 0.84, CHCl_3 , from 91% ee of *E*-**15**). HPLC Anal. $t_{\text{R}}/\text{min}=14.1$ (*S*), 17.6 (*R*); (*S*):(*R*)=4.6:95.4 (*n*-Hexane, flow: 1.0 mL/min, CHIRALPAK AD).

4-Methyl-2-(2-phenethyl)-2-(trifluoromethyl)pentanal (**11ab**)

^1H NMR δ 0.91 (3 H, d, $J=6.6$ Hz), 0.95 (3 H, d, $J=6.6$ Hz), 1.75–1.86 (3 H, m), 1.91-2.19 (2 H, m), 2.56-2.73 (2 H, m), 7.180-7.33 (5 H, *aromatic*), 9.73 (1 H, q, $J=1.5$ Hz); ^{13}C NMR δ 23.96 (q, $J=0.9$ Hz), 24.04, 24.41, 30.03 (q, $J=1.6$ Hz), 31.73 (q, $J=1.5$ Hz), 38.25 (q, $J=1.7$ Hz), 58.35 (q, $J=21.8$ Hz), 126.17, 126.67 (q, $J=284.8$ Hz), 128.11, 128.45, 140.99 (q, $J=0.6$ Hz), 197.34 (q, $J=2.6$ Hz); ^{19}F NMR δ 93.93 (s). IR (neat) ν 3065, 3028, 2963, 2874, 2732, 1739, 1654, 1604, 1560, 1542, 1497, 1457, 1390, 1370, 1320, 1245, 1214, 1168, 1141, 1051, 853, 745, 699 cm^{-1} .

2-Ethyl-2-(trifluoromethyl)decanal (**11ba**)

^1H NMR δ 0.88 (3 H, t, $J=6.9$ Hz), 0.93 (3 H, qt, $J=1.2$, 7.6 Hz), 1.27 (12 H, bs), 1.71-1.92 (4 H, m), 9.62 (1 H, q, $J=1.4$ Hz); ^{13}C NMR δ 7.93 (q, $J=1.2$ Hz), 14.09, 21.17 (q, $J=1.9$ Hz), 22.67, 23.19 (q, $J=1.1$ Hz), 28.87 (q, $J=1.6$ Hz), 29.22, 29.27, 30.20, 31.84, 58.28 (q, $J=21.66$ Hz), 126.79 (q, $J=284.6$ Hz), 197.32 (2.7 Hz); ^{19}F NMR δ 93.60 (s). IR (neat) ν 2955, 2928, 2855, 2731, 1739, 1462, 1377, 1323, 1242, 1173, 1142, 1107, 995, 783, 721 cm^{-1} .

2-Isobutyl-2-(trifluoromethyl)decanal (**11bb**)

^1H NMR δ 0.88 (3 H, t, $J=6.9$ Hz), 0.89 (3 H, d, $J=6.6$ Hz), 0.92 (3 H, t, $J=6.6$ Hz), 1.27 (13 H, bs), 1.58-1.82 (4 H, m), 9.66 (1 H, q, $J=1.6$ Hz); ^{13}C NMR δ 13.25, 21.84, 22.58 (q, $J=1.2$ Hz), 23.14 (q, $J=1.0$ Hz), 23.29, 23.44, 28.39, 28.44, 28.91 (q, $J=1.6$ Hz), 29.46, 31.00, 37.27 (q, $J=1.5$ Hz), 57.43 (q, $J=21.6$ Hz), 125.87 (q, $J=284.8$ Hz), 196.98 (q, $J=2.6$ Hz); ^{19}F NMR δ 93.75 (s). IR (neat) ν 2959, 2928, 2854, 2731, 1739, 1466, 1392, 1369, 1323, 1234, 1172, 1138, 1061, 1026, 964, 852, 756, 725, 671 cm^{-1} .

2-Phenyl-2-(trifluoromethyl)decanal (**11ca**)

^1H NMR δ 0.84-0.89 (3 H, m), 1.24 (12 H, bs), 2.16-2.31 (2 H, m), 7.26-7.47 (5 H, *aromatic*), 9.74 (1 H, q, $J=2.2$ Hz); ^{13}C NMR δ 14.08, 22.62, 23.75 (q, $J=1.2$ Hz), 29.12, 29.14, 30.16, 30.19, 31.76, 62.76 (q, $J=22.6$ Hz), 125.48 (q, $J=284.1$ Hz), 128.40 (q, $J=1.1$ Hz), 128.57, 128.81, 131.36 (q, $J=1.2$ Hz), 194.73 (q, $J=1.8$ Hz); ^{19}F NMR δ 94.33 (d, $J=2.6$ Hz). IR (neat) ν 3036, 2919, 2849, 2743, 1737, 1496, 1467, 1378, 1331, 1243, 1161, 1067, 1032, 1008, 761, 697 cm^{-1} .

Preparation of (*E*)-6-phenyl-4-(trifluoromethyl)-3-hexen-2-one (**12**)

(Acetylmethylene)triphenylphosphorane 1.050 g (3.3 mmol) was added to solution of **3a** (3 mmol) in THF (15 mL) under an argon atmosphere and the solution was refluxed for 30 min. After cooling to room temperature, the reaction mixture was concentrated under vacuum, filtrated, and the

residue was washed with *n*-hexane. The crude product was purified by silica gel column chromatography to give 0.632 g of **12** (2.6 mmol, 87% yield). ¹H NMR δ 2.22 (3 H, s), 2.77-2.90 (4 H, m), 6.64 (1 H, q, *J*=1.6 Hz), 7.17-7.34 (5 H, *aromatic*); ¹³C NMR δ 28.90 (q, *J*=1.0 Hz), 31.49, 34.83, 123.49 (q, *J*=274.6 Hz), 125.99, 127.71 (q, *J*=5.5 Hz), 128.20, 128.35, 140.38, 141.81 (q, *J*=28.7 Hz), 197.15; ¹⁹F NMR δ 92.75 (d, *J*=1.7 Hz). IR (neat) ν 3066, 3032, 2943, 2870, 1701, 1639, 1458, 1357, 1307, 1273, 1203, 1165, 1126, 1053, 871, 698 cm⁻¹. Anal. Calcd for C₁₃H₁₃F₃O: C, 64.46; H, 5.41. Found: C, 64.05, H, 5.88.

Preparation of (2*R*,3*E*)-6-phenyl-4-(trifluoromethyl)-3-hexen-2-ol (13**)²**

To a three-neck flask equipped with pressure equalizing dropping funnel was added 50 mL of LiAlH₄ (50 mmol, 1.0 mol/L in THF) under an argon atmosphere and EtOH (3.0 mL, 51.1 mmol) in THF (25 mL) was added dropwise over a period of *ca.* 1 h. After addition was completed, the solution of 14.317 g of (*R*)-(+)-binaphthol (50.0 mmol) in THF (84 mL) was introduced dropwise over the period of *ca.* 1 h, and the resulting mixture was stirred at room temperature for 30 min. After cooling to -78 °C, the solution of ketone **12** (25 mmol) in THF (50 mL) was added dropwise and stirred at -78 °C for 24 h. 5 mL of MeOH and 2.5 mL of water were added at that temperature, and the reaction mixture was warmed to room temperature. The resulting mixture was stirred with ether for 1 h and treated with anhydrous MgSO₄ and filtrated. The crude product was purified by alumina and silica gel column chromatography successively. ¹H NMR δ 1.06 (3 H, d, *J*=6.4 Hz), 2.55-2.58 (2 H, m), 2.77-2.87 (2 H, m), 4.14 (1 H, qd, *J*=6.3, 9.2 Hz), 6.01 (1 H, qd, *J*=1.6, 9.2 Hz), 7.76-7.35 (5 H, *aromatic*); ¹³C NMR δ 22.27 (q, *J*=1.0 Hz), 27.90 (q, *J*=0.6 Hz), 34.80, 63.43, 124.29 (q, *J*=273.6 Hz), 126.34, 128.40, 128.72, 127.89 (q, *J*=28.1 Hz), 137.96 (q, *J*=5.7 Hz), 140.43; ¹⁹F NMR δ 95.23 (s). IR (neat) ν 3356, 3029, 2973, 2863, 1718, 1676, 1654.2, 1603.9, 1542.3, 1497.2, 1454.7, 1328.3, 1279.7, 1189.0, 1167.7, 1114.9, 1063.3, 1026.6, 940.1, 894.4, 862.2, 773.8, 747.3, 700.0 cm⁻¹. [α]_D¹⁹ -22.77° (*c* 1.08, MeOH; 91% ee). HPLC Anal. *t*_R/min=19.6 (*S*), 21.7 (*R*) (*n*-Hexane:*i*-PrOH=99:1, flow:1.0ml/min, CHIRALPAK AD), (*S*):(*R*)=4.6:95.4. Anal. Calcd for C₁₃H₁₅F₃O: C, 63.93; H, 6.19. Found: C, 63.78, H, 5.98.

(2*R*,3*E*)-6-phenyl-4-(trifluoromethyl)-3-hexen-2-yl acetate (14**)**

To a round bottom flask containing allylic alcohol **13** (15.0 mmol) and CH₂Cl₂ (30 mL) were added a catalytic amount of DMAP (10 mol%), 1.7 mL of acetic anhydride (18.0 mmol), followed by addition of 2.5 mL of triethylamine (18.0 mmol) at 0 °C. After addition, the solution was warmed to room temperature and stirred for 1 h, and was quenched with saturated NH₄Cl aq. After separation of the two layers, the aqueous solution was extracted with CH₂Cl₂ twice and the combined organic layer was washed with brine, dried (MgSO₄) and concentrated under vacuum. The resulting mixture was purified by silica gel column chromatography. ¹H NMR δ 1.04 (3 H, d, *J*=6.6 Hz), 2.02 (3 H, s), 2.49-2.92 (4 H, m), 5.39 (1 H, qd, *J*=6.5, 9.4 Hz), 5.99 (1 H, qd, *J*=1.7, 9.3 Hz), 7.17-7.33 (5 H, *aromatic*); ¹³C NMR δ 19.62, 20.91, 28.22 (q, *J*=0.6 Hz), 34.67, 65.86, 124.02 (q, *J*=273.6 Hz), 126.09, 128.31, 128.42, 130.47 (q, *J*=28.2 Hz), 133.38 (q, *J*=6.0 Hz), 140.30, 169.60; ¹⁹F NMR δ 94.79 (s). IR (neat) ν 3064, 3029, 2984, 2936, 2873, 1743, 1654, 1604, 1560, 1542, 1496, 1454, 1372, 1343, 1283, 1237, 1190, 1172, 1143, 1117, 1051, 1029, 955, 893, 846, 796, 746, 700 cm⁻¹. [α]_D²⁶ -48.88° (*c* 1.16, CHCl₃, from 91% ee of **13**). Anal. Calcd for C₁₅H₁₇F₃O₂: C, 62.93; H, 5.99. Found: C, 63.05, H, 5.88.

(*E*)-4-Ethyl-6-phenyl-4-(trifluoromethyl)-2-hexene (E-15**)**

¹H NMR δ 0.95 (3 H, qt, *J*=1.2, 7.6 Hz), 1.65-2.10 (4 H, m), 1.77 (3 H, dd, *J*=1.7, 6.6 Hz), 2.51-2.75 (2 H, m), 5.40 (1 H, d, *J*=15.9 Hz), 5.69 (1 H, qd, *J*=6.4, 15.9 Hz), 7.17-7.33 (5 H, *aromatic*); ¹³C NMR δ 8.01 (q, *J*=1.3 Hz), 18.47, 24.30 (q, *J*=1.9 Hz), 29.99 (q, *J*=1.3 Hz), 33.41, 48.18 (q, *J*=22.6 Hz), 125.79, 128.09, 128.29, 128.30, 128.42 (q, *J*=284.1 Hz), 128.73 (q, *J*=2.3 Hz), 142.02; ¹⁹F NMR δ 89.69 (s). IR (neat) ν 3028, 2970, 2929, 2885, 1717, 1654, 1604, 1560, 1497, 1456, 1382, 1348, 1322, 1243, 1209, 1164, 1137, 1031, 1008, 974, 910, 902, 751, 738, 699 cm⁻¹. [α]_D²² 14.7° (*c* 1.05, CHCl₃, from 91% ee of **14**). Anal. Calcd for C₁₅H₁₉F₃: C, 70.29; H, 7.47. Found C, 69.88; H, 7.62.

2-Ethyl-4-phenyl-2-(trifluoromethyl)butylamine

To a round bottom flask equipped with Dean-Stark apparatus and reflux condenser were added 0.366 g of aldehyde **16** (1.50 mmol) and benzene (30 ml), 0.39 ml of benzylamine (3.57 mmol) and a catalytic amount of *p*-toluenesulfonic acid monohydrate, and the whole mixture was refluxed for 8 h. The resultant salt was filtered off and the residue was washed with ether. After concentration under vacuum, the crude product was dissolved in MeOH (5.0 mL). To the solution was added at 0 °C 0.340 g of NaBH₄ (9.0 mmol) and the mixture was stirred overnight at room temperature. The solution was quenched with 3 *N* HCl aq. which was then basified by sat. NaHCO₃ aq. After separation of the two layers, the aqueous solution was extracted with ether twice and the combined organic layer was washed with brine, dried (Na₂SO₄) and concentrated under vacuum. The resulting product was purified by silica gel column chromatography to give 0.487 g of the desired benzyl 2-ethyl-4-phenyl-2-(trifluoromethyl)butylamine (1.45 mmol) in 97% yield.

To a solution of 0.129 g of Pd/C (10% on carbon) in MeOH (1.2 mL) containing 4.4% HCO₂H was added 0.406 g of the above amine (1.21 mmol) in 1.2 mL MeOH (containing 4.4% HCO₂H) under argon atmosphere. After stirring for 18 h at room temperature, the reaction mixture was filtered through Celite and washed with ethyl acetate. The solution was washed with sat. NaHCO₃ aq., and the aqueous solution was extracted with ethyl acetate twice and the combined organic layer was washed with brine, dried (Na₂SO₄) and concentrated under vacuum. The resulting product was purified by silica gel column chromatography to give 0.288 g of the desired amine (1.17 mmol) in 97% yield. ¹H NMR δ 0.84 (3 H, qt, *J*=1.2, 7.6 Hz), 1.69 (3 H, q, *J*=7.6 Hz), 1.76-1.89 (2 H, m), 2.63 (2 H, t, *J*=8.9 Hz), 2.88 (2 H, s), 7.18-7.33 (5 H, *aromatic*); ¹³C NMR δ 7.84 (q, *J*=1.2 Hz), 22.68 (q, *J*=2.1 Hz), 29.81 (q, *J*=1.4 Hz), 32.44 (q, *J*=1.8 Hz), 44.23 (q, *J*=2.4 Hz), 47.10 (q, *J*=20.23 Hz), 125.88, 128.06, 128.34, 129.41 (q, *J*=285.4 Hz), 141.79; ¹⁹F NMR δ 92.23 (s). IR (neat) ν 3406, 3348, 3062, 3028, 2966, 2943, 2885, 1870, 1685, 1627, 1604, 1543, 1496, 1458, 1388, 1311, 1249, 1149, 1130, 1064, 1029, 1014, 960, 906, 756, 732, 698 cm⁻¹. [α]_D²⁵ 1.19° (*c* 0.69, CHCl₃, from 85% ee of **13**). Anal. Calcd for C₁₃H₁₈F₃N: C, 63.66; H, 7.40; N, 5.71. Found: C, 63.05; H, 7.41; N, 5.45.

Preparation of *N*-2-ethyl-4-phenyl-2-(trifluoromethyl)butyl (1*S*)-10-camphorsulfonamide (**17**)

The above amine (0.25 mmol) in CH₂Cl₂ (1.0 mL) was placed in a two-necked flask with stir bar under an argon atmosphere where 125 mg of (+)-10-camphorsulfonyl chloride (0.50 mmol) and 0.07 mL of triethylamine (0.50 mmol) were added at 0 °C. The reaction mixture was allowed to warm to room temperature and stirred overnight. The solution was quenched with sat. NaHCO₃ aq. and after separation of the two layers, the aqueous solution was extracted with CH₂Cl₂ twice and the combined organic layer was washed with brine, dried (MgSO₄) and concentrated under vacuum. The resulting product was purified by silica gel column chromatography to give 84 mg of the desired camphorsulfonamide **17** (0.18 mmol) in 73% yield as a yellow solid. ¹H NMR δ 0.93 (3 H, s), 1.02 (3 H, s), 1.04 (3 H, qt, *J*=1.1, 7.4 Hz), 1.66-1.83 (2 H, m), 1.85-2.23 (8 H, m), 2.37-2.46 (1 H, m), 2.56-2.81 (2 H, m), 2.95 (1 H, d, *J*=15.1 Hz), 3.14 (1 H, d, *J*=15.1 Hz), 3.35 (2 H, d, *J*=6.9 Hz), 7.16-7.32 (5 H, *aromatic*); ¹³C NMR δ 7.91 (q, *J*=1.4 Hz), 19.39, 19.93, 23.65 (q, *J*=2.3 Hz), 26.94, 27.00, 29.19 (q, *J*=1.4 Hz), 31.58, 42.75, 42.92, 44.96 (q, *J*=2.3 Hz), 46.54 (q, *J*=21.7 Hz), 48.95, 49.88, 59.29, 125.84, 128.18, 128.28, 128.68 (q, *J*=285.4 Hz), 141.39, 217.05; ¹⁹F NMR δ 91.39 (s). IR (KBr) ν 3448, 3278, 3028, 2958, 2893, 1735, 1458, 1392, 1334, 1276, 1253, 1203, 1172, 1134, 1107, 1068, 1045, 964, 910, 825, 763, 698, 678 cm⁻¹. [α]_D²⁵ 32.72° (*c* 0.10, CHCl₃, from 85% ee of **13**). Anal. Calcd for C₂₃H₃₂F₃NO₃S: C, 60.11; H, 7.02; N, 3.05. Found: C, 60.61; H, 7.51; N, 2.68. mp. 74-75 °C.

¹ Shen, Y.; Gao, S. *J. Org. Chem.* **1993**, 58, 4564.

² Preparation of BINAL-H reagent and asymmetric reduction was see; Noyori, R.; Tomino, Y.; Tanimoto, Y.; Nishizawa, M. *J. Am. Chem. Soc.* **1984**, 106, 6709.