Supplementary Material (ESI) for Chemical Communications

Supplementary Information

for

Activation of Organozinc Reagents with t-Bu-P4 Base For Transition Metal-Free Catalytic S_N2' Reaction

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General Comments.

Reactions were carried out under Ar atmosphere using dry solvents. Melting points (mp) were determined with a Yazawa micro melting point apparatus and uncorrected. Infrared (IR) data were recorded on SensIR ATR (Attenuated Total Reflectance) FT-IR. The spectra were acquired in 32 scans per spectrum at a resolution of four using system ReactIR™ 2.20 software. Absorbance frequencies are reported in reciprocal centimeters (cm^{-1}). NMR data were recorded on either a JEOL AL400 spectrometer (395.75 MHz for ^{1}H, 99.50 MHz for ^{13}C). Chemical shifts are expressed in δ (parts per million, ppm) values, and coupling constants are expressed in herts (Hz). ^{1}H NMR spectra were referenced to a tetramethylsilane as an internal standard or to a solvent signal ($CDCl_3$: 7.26 ppm). ^{13}C NMR spectra were referenced to a tetramethylsilane as an internal standard or to a solvent signal ($CDCl_3$: 77.0 ppm). The following abbreviations are used: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, dd = double doublet, dt = double triplet, td = triple doublet, dq = double quartet, br = broad singlet. Low and high resolution mass spectra (LRMS and HRMS) were obtained from Mass Spectrometry Resource, Graduate School of Pharmaceutical Sciences, Tohoku University, on a JEOL JMS-DX303 and JMS-700 spectrometer respectively.

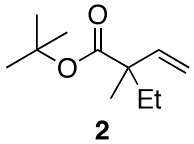
Materials.

Unless otherwise noted, materials were purchased from Tokyo Kasei Co., Aldrich Inc., and other commercial suppliers and were used after appropriate purification (distillation or recrystallization). Flash column chromatographies were performed with Kanto silica gel 60 N (spherical, neutral, 70−230 mesh).

General Procedure

Under argon atmosphere, *t*-Bu-P4 base (0.03 mL 1.0 M in hexane, 0.03 mmol) was added to a mixture of electrophile (0.3 mmol), diethyl zinc (0.60 mL 0.6 mmol), LiCl (1.3 mg 0.03 mmol) and dry DMF (0.4 mL) at 0 ˚C and the mixture was stirred 2-8 h at 0 ˚C. After the reaction, saturated aq. NH_4Cl and H_2O were added to the mixture. The mixture was extracted with AcOEt or Et_2O (30 mL x 3). The combined organic layers were then washed with saturated aq. NaCl (50 mL). The solution was dried with $MgSO_4$, filtered, and concentrated *in vacuo*. The crude material was purified by SiO_2 column chromatography. All γ-chloro-α,β-unsaturated esters were synthesized using literature procedures[1].

***tert*-Butyl 2-ethyl-2-methylbut-3-enoate 2**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (49.8 mg, 90%).



2

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.85 (t, *J* = 7.5 Hz, 3H), 1.44 (s, 9H), 1.49 (s 3H), 1.49-1.88 (m, 1H,),

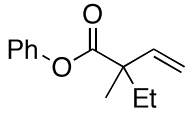
1.68-1.80 (m, 1H), 5.02-5.09 (m, 2H), 5.98 (dd, J = 18.1 Hz, J = 10.5 Hz, 1H).

LRMS (EI) *m/z* 184 (M^+)

HRMS: Calcd. For $C_{11}H_{20}O_2$: 184.1463, Found: 184.1447

IR (neat): 2973, 2933, 1725, 1459, 1368, 1246, 1136, 914, 850 cm^{-1}

Phenyl 2-Ethyl-2-methyl-3-enoate 2a: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (53.3 mg, 87%).



2a

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm): 0.98 (t, J = 7.2 Hz, H), 1.38 (s, 3H), 1.70-1.82 (m, 1H), 1.90-2.11 (m, 1H), 5.17-5.27 (m, 2H), 6.14 (dd, J = 17.6 Hz, J = 10.8 Hz, 1H), 7.04 (d, J = 7.6 Hz, 2H), 7.21(t, J = 7.6 Hz, 1H), 7.35 (t, J = 7.6 Hz, 2H).

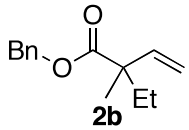
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm): 9.1, 20.0, 31.9, 49.2, 114.2, 121.4, 125.6, 129.2, 141.0, 150.9, 174.2.

LRMS (EI) *m/z*: 204 (M^+).

HRMS: Calcd. for $C_{13}H_{16}O_2$: 204.1150. Found: 204.1149.

IR (neat): 2977, 1723, 1640, 1457, 1368, 1167, 1136, 914, 849, 766 cm^{-1}.

Benzyl 2-ethyl-2-methylbut-3-enoate 2b: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as yellowish oil (60.9 mg, 93%).



2b

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.83 (t, J = 7.6 Hz, 3H), 1.28(s, 3H), 1.58-1.69 (m, 1H), 1.74-1.83 (m, 1H), 5.05-5.19 (m, 2H), 5.12 (s, 2H), 6.03 (dd, J = 17.4 Hz, J = 10.8 Hz, 1H), 7.27-7.38 (m, 5H)

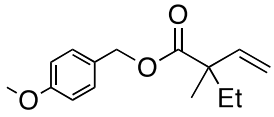
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm): 8.9, 19.9, 31.9, 49.0, 66.2, 113.7, 127.7, 128.4, 136.1, 141.3, 175.4.

LRMS (EI) *m/z* 218 (M^+)

HRMS: Calcd. for $C_{14}H_{18}O_2$: 218.1307, Found: 218.1325.

IR (neat): 2970, 1727, 1457, 1231, 1133, 1003, 916, 731, 696 cm^{-1}

***para*-Methoxybenzyl 2-ethyl-2-methylbut-3-enoate 2c**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (67.8 mg, 91%).



2c

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm): 0.81 (t. *J* = 7.2 Hz, 3H), 1.26 (s, 3H), 1.55-1.67 (m, 1H), 1.71-1.83 (m, 1H), 3.81 (s, 3H), 5.01-5.12 (m, 4H), 6.01 (dd, *J* = 17.6 Hz, *J* = 11.2 Hz, 1H), 6.87 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H).

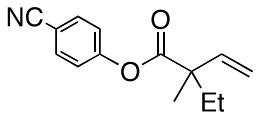
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm): 8.9, 19.9, 31.9, 49.0, 55.2, 66.1, 113.5, 113.8, 128.3, 129.6, 141.4, 159.3, 175.5.

LRMS (EI) *m/z*: 248 (M^+).

HRMS: Calcd. for $C_{15}H_{20}O_3$: 248.1412. Found: 248.1395.

IR (neat): 2966, 1725, 1613, 1515, 1459, 1245, 1133, 1034, 920, 822 cm^{-1}.

***para*-Cyanophenyl 2-ethyl-2-methylbut-3-enoate 2d**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (57.8 mg, 84%).



2d

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm): 0.97 (t, *J* = 7.2 Hz, 3H), 1.40 (s, 3H), 1.71-1.82 (m, 1H), 1.90-2.00 (m, 1H), 5.19-5.26 (m, 2H), 6.09 (dd, *J* = 17.2 Hz, *J* = 10.4 Hz, 1H), 7.19 (d, *J* = 8.8 Hz, 2H), 7.68 (d, *J* = 8.8 Hz, 2H).

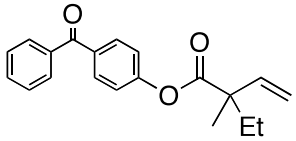
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm): 9.0, 19.9, 31.8, 49.3, 109.5, 114.8, 118.1, 122.6, 133.5, 140.2, 154.2, 173.4.

LRMS (EI) *m/z*: 229 (M^+).

HRMS: Calcd. for $C_{14}H_{15}NO_2$: 229.1103. Found: 229.1103.

IR (neat): 2970, 2231, 1752, 1602, 1497, 1206, 1167, 1092, 901, 862 cm^{-1}.

***para*-Benzoylphenyl 2-ethyl-2-methylbut-3-enoate 2e**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (81.4 mg, 88%).



2e

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm): 0.99 (t, *J* = 7.6 Hz, 3H), 1.42 (s, 3H), 1.73-1.84 (m, 1H), 1.92-2.02 (m, 1H), 5.21-5.28 (m, 2H), 6.13 (dd, *J* = 17.6 Hz, *J* = 10.4 Hz, 1H), 7.17 (d, *J* = 8.8 Hz, 2H), 7.48 (t, *J* = 7.6 Hz, 2H), 7.59 (t, *J* = 7.6 Hz, 1H), 7.79 (d, *J* = 7.6 Hz, 2H), 7.85 (d, *J* = 8.8 Hz, 2H).

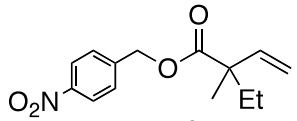
$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ (ppm): 9.0, 20.0, 31.8, 49.3, 114.6, 121.3, 128.2, 129.8, 131.5, 132.3, 134.8, 137.6, 140.5, 154.1, 173.7, 195.2.

LRMS (EI) *m/z*: 308 (M^+).

HRMS: Calcd. for $C_{20}H_{20}O_3$: 308.1412. Found: 308.1399.

IR (neat): 2968, 1750, 1657, 1598, 1275, 1200, 1148, 1098, 924, 735, 704 cm^{-1}.

***para*-Nitrobenzyl 2-ethyl-2-methylbut-3-enoate 2f**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as yellow oil (52.1 mg, 66%).



2f

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.84(t, *J* = 7.6 Hz, 3H), 1.31(s, 3H), 1.61-1.72(m, 1H), 1.77-1.87(m, 1H), 5.09-5.29(m, 2H), 5.21(s, 2H), 6.02(dd, *J* = 17.6 Hz, 10.8 Hz, 1H), 7.49(d, *J* = 9.2 Hz, 2H), 8.22(d, *J* = 9.2 Hz, 2H).

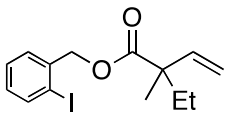
$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$/TMS) δ (ppm) : 8.92, 19.80, 31.78, 49.02, 64.77, 114.12, 123.64, 127.98, 140.86, 143.36, 147.44, 175.14.

LRMS (EI) *m/z* 263 (M^+)

HRMS: Calcd. For $C_{14}H_{17}NO_4$: 263.1158, Found 263.1158.

IR (neat): 3085, 2970, 1729, 1607, 1520, 1345, 1229, 1111, 735 cm^{-1}.

***ortho*-Iodobenzyl 2-ethyl-2-methylbut-3-enoate 2g**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 8:2) to give the title compound as colorless oil (90.9 mg, 88%).



2g

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.85(t, *J* = 7.6 Hz, 3H), 1.31(s, 3H), 1.61-1.72(m, 1H), 1.78-1.88(m, 1H), 5.08-5.20(m, 2H), 5.12(s, 2H), 6.65(dd, *J* = 17,6 Hz, *J* = 10.8 Hz, 1H), 7.01(td, *J* = 6.8 Hz, *J* = 2.4 Hz, 1H), 7.31-7.39(m, 2H), 7.84(d, *J* = 7.6 Hz, 1H).

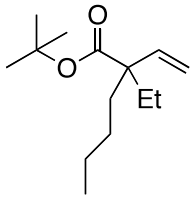
$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$/TMS) δ (ppm) : 8.93, 19.83, 31.83, 49.11, 70.10, 98.14, 113.89, 128.23, 129.26, 129.66, 138.52, 139.42, 141.32, 175.30.

LRMS (EI) *m/z* 344 (M^+)

HRMS: Calcd. For $C_{14}H_{17}IO_2$: 344.0273, Found 344.0287.

IR (neat): 3064, 2970, 1727, 1459, 1437, 1229, 1129, 1015, 918, 746 cm^{-1}.

***tert*-Butyl 2-butyl-2-ethylbut-3-enoate 2h**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (59.8 mg, 88%).



2h

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.89(t, *J* = 7.2 Hz, 3H), 1.16-1.35(m, 4H), 1.21(s, 3H), 1.43(s, 9H), 1.49-1.58(m, 2H), 1.62-1.72(m, 1H), 5.01-5.08(m, 2H), 5.99(dd, *J* = 17.6 Hz, *J* = 10.8 Hz, 1H)

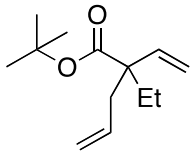
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$/TMS) δ (ppm) : 14.04, 20.49, 23.23, 26.84, 28.02, 39.03, 49.08, 80.11, 112.72, 142.44, 174.98

LRMS (EI) *m/z* 212 (M^+)

HRMS: Calcd. For $C_{13}H_{24}O_2$: 212.1776, Found 212.1774.

IR (neat): 2958, 2933, 1725, 1459, 1366, 1272, 1254, 1135, 914, 850 cm^{-1}.

***tert*-Butyl 2-ethyl-2-(2-propenyl)but-3-enoate 2i**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as yellow oil (46.7 mg, 74%).



2i

^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm): 0.83 (t, *J* = 7.2 Hz, 3H), 1.44 (s, 9H), 1.69 (q, *J* = 7.2 Hz, 2H), 2.42 (d, *J* = 7.2 Hz, 2H), 5.00-5.20 (m, 4H), 5.64-5.76 (m, 1H), 5.94 (dd, *J* = 17.6 Hz, *J* = 10.8 Hz, 1H).

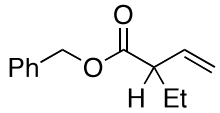
^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ (ppm): 8.6, 28.1, 28.6, 39.9, 52.7, 80.4, 114.3, 117.4, 134.1, 139.9, 173.8.

LRMS (EI) *m/z*: 210 (M^+).

HRMS: Calcd. for $C_{13}H_{22}O_2$: 210.1620 Found: 210.1578.

IR (neat): 2977, 1723, 1640, 1368, 1243, 1167, 1136, 914, 849 cm^{-1}.

Benzyl 2-ethylbut-3-enoate 2j: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (57.6 mg, 94%).



2j

400 MHz ^{1}H NMR ($CDCl_3$/TMS) δ (ppm) : 0.90 (t, *J* = 7.6 Hz, 3H), 1.54-1.65 (m, 1H), 1.75-1.87 (m, 1H), 2.97 (dt, *J* = 8.3 Hz, *J* = 7.3 Hz, 1H), 5.10-5.20 (m, 4H), 5.76-5.88 (m, 1H), 7.30-7.39 (m, 5H).

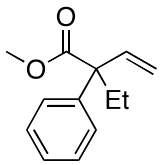
$^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ (ppm): 11.6, 25.4, 51.9, 66.2, 117.2, 127.9, 128.0, 128.4, 135.7, 135.9, 173.7.

LRMS (EI) *m/z* 204 (M^+)

HRMS: Calcd. For $C_{13}H_{16}O_2$: 204.1150, Found: 204.1137.

IR (neat): 2694, 1733, 1457, 1167, 1144, 991, 920, 735, 696 cm^{-1}

Methyl 2-ethyl-2-phenylbut-3-enoate 2k: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 20:1) to give the title compound as colorless oil (23.3 mg, 38%).



2k

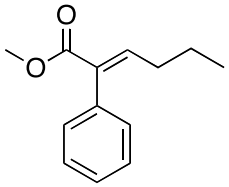
^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.83(t, *J* = 7.6 Hz, 3H), 2.07-2.27(m, 2H), 3.69(s, 3H), 5.02(d, *J* = 18.0 Hz, 1H), 5.31(d, *J* = 10.8 Hz, 1H), 6.38(dd, *J* = 18.0 Hz, *J* = 10.8 Hz, 1H), 7.20-7.27(m, 3H), 7.29-7.35(m, 5H).

LRMS (EI) *m/z* 204 (M^+)

HRMS: Calcd. For $C_{13}H_{16}O_2$: 204.1150, Found 204.1149.

IR (neat): 3087, 2950, 1731, 1459, 1434, 1227, 1123, 739, 698 cm^{-1}.

Methyl 2-phenyl-2-hexenoate The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 20:1) to give the title compound as colorless oil (37.4 mg, 61%).



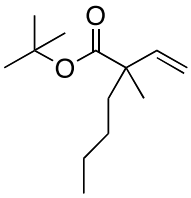
^{1}H NMR (400 MHz, $CDCl_3$/TMS) δ (ppm) : 0.87(t, *J* = 7.2 Hz, 3H), 1.44(m, 2H), 2.05(q, *J* = 7.6 Hz, 2H), 3.72(s, 3H), 7.08(t, *J* = 7.6 Hz, 1H), 7.13-7.19(m, 2H), 7.30-7.40(m, *J* = 3H).

LRMS (EI) *m/z* 204 (M^+)

HRMS: Calcd. For $C_{13}H_{16}O_2$: 204.1150, Found 204.1144.

IR (neat): 2958, 1715, 1495, 1434, 1245, 1223, 1023, 764, 700 cm^{-1}.

***tert*-Butyl 2-buthyl-2-ethylbut-3-enoate 2l**: The crude material was purified by column chromatography on silica gel (eluting with hexane/ethyl acetate = 10:1) to give the title compound as colorless oil (47.1 mg, 74%).



2l

400 MHz ^{1}H NMR ($CDCl_3$/TMS) δ (ppm) : 0.89(t, *J* = 7.2 Hz, 3H), 1.16-1.35(m, 4H), 1.21(s, 3H), 1.43(s, 9H), 1.49-1.58(m, 2H), 1.62-1.72(m, 1H), 5.01-5.08(m, 2H), 5.99 (dd, *J* = 17.6 Hz, *J* = 10.8 Hz, 1H)

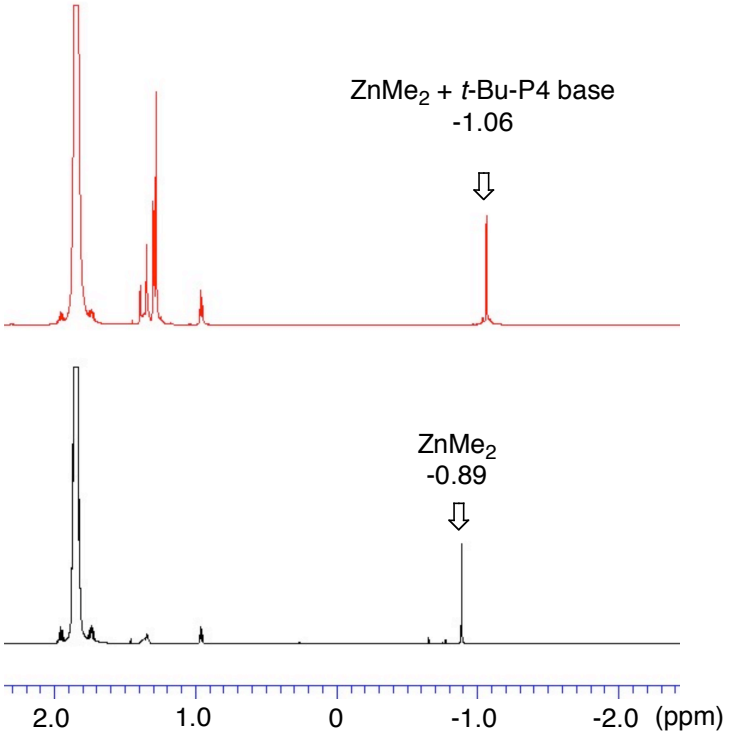
100 MHz ^{13}C{^{1}H} NMR ($CDCl_3$/TMS) δ (ppm) : 14.04, 20.49, 23.23, 26.84, 28.02, 39.03, 49.08, 80.11, 112.72, 142.44, 174.98

IR (cm^{-1}): 2958, 2933, 1725, 1459, 1366, 1272, 1254, 1135, 914, 850

LRMS (EI) *m/z* 212 (M^+)

HRMS: Calcd. For $C_{13}H_{24}O_2$: 212.1776, Found 212.1774

1H-NMR Spectra of Dimethylzinc in THF (–20 ˚C)



Reference

[1] Lee, Y.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2006**, *128*, 15604-15606.