The First Practical Additive-Free 1,4-Conjugated Alkylation of Fluoroalkylated Electron-Deficient Olefins with Various Organozinc Reagents

Atsunori Morigaki,a Tomotsugu Miyabe,b Kazuki Tsukade,b Satoru Arimitsu,c Takashi Ishihara,b Tsutomu Konno*b

a Functional Materials Research Laboratories Research & Development Headquarters LION CORPORATION, 7-2-1 Hirni, Edogawa-ku, Tokyo 132-0035, Japan
b Department of Chemistry and Materials Technology, Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-0962, Japan
Fax +81(75)7247580; E-mail: konno@chem.kit.ac.jp
c Department of Chemistry Biology and Marine Science, University of the Ryukyus, Nishihara, Okinawa 903-0123, Japan

Received: 30.09.2012; Accepted after revision: 08.11.2012

Abstract: 1,4-Conjugated alkylation of fluoroalkylated olefins with organozinc reagents, such as RZnI and R₂Zn, was conducted smoothly to give the corresponding products in moderate yields without the use of either transition metals or Lewis acids. This reaction protocol allows not only a wide range of alkyl groups but also electron-withdrawing groups to be incorporated as 1,4-conjugated adducts.

Key words: 1,4-conjugated alkylation, organozinc reagents, trifluoromethyl, electron-deficient olefin

The carbon–carbon bond formation through 1,4-conjugated alkylation has been recognized as one of the most important organic reactions. In the last decade, numerous synthetic methodologies have been developed for this transformation. Especially the transition-metal-catalyzed 1,4-conjugated addition has been intensively investigated and applied for enantioselective versions in several successful examples. Among these developments, the metal nucleophile also has been studied for expanding substrate scopes under the milder reaction condition. The organozinc reagents (i.e., RZnX, R₂Zn, and R₃ZnMet) are known as unique nucleophiles compared to other common organometallic reagents, that is, the softer nucleophilicity of organozinc reagents shows higher functional-group tolerance. However, organozinc reagents often require the assistance of transition metals or Lewis acids in order to react as expected.

Tremendous attention has been paid to fluorine-containing molecules because of their biological properties as well as their unique reactivities, which has led to new developments of synthetic methodologies. For example, trifluoromethyl-bearing olefins, such as 1 in Scheme 1, shows very interesting LUMO-lowering effect on its β-carbon. We and Yamazaki et al. have demonstrated that the electron-deficient olefin 1 can serve as an excellent reaction partner for 1,4-conjugated addition, but incoming substrates for these reactions are to some extent limited. In fact, the introduction of simple alkyl substrates has been facing many difficulties, such as defluorination and a narrow range of the substrate scope. To overcome this limitation, we revisited the basic nature of olefin 1, and realized that it will be possible for even unreactive nucleophiles to react with olefin 1 without addition of any activators (i.e., transition metals and Lewis acids). Herein, we describe the first practical 1,4-conjugated alkylation of fluoroalkylated olefins 1 with organozinc reagents under the additive-free conditions.

Initially, the least reactive organozinc reagents, alkylzinc halides, were chosen for the 1,4-conjugated alkylation to (E)-4,4,4-trifluoro-1-phenylbut-2-en-1-one (1a). Thus, the olefin 1a was treated with 3.0 equivalents of freshly prepared RZnI in THF at 0 °C and then the reaction mixture was stirred for eight hours at the same temperature. To our surprise, the reaction gave the corresponding 1,4-adduct in a moderate yield without extra additive (Table 1, entries 1 and 3). Next, the same reaction was tested with dialkylzinc reagents, which gave a smoother reaction and higher yield of the product in only one hour at −78 °C (entries 2 and 4). Interestingly, when the organozincate, (n-Bu)₂ZnLi, was utilized in this reaction, its 1,2-adduct was obtained instead as the major product (entry 5). This reaction trend of organozinc reagents was observed similarly in other substrates; therefore, RZnI and R₂Zn were used for further reactions. Dialkylzinc reagents were found to be the most effective, and even sterically hindered alkyl groups, such as i-Pr and t-Bu, could be introduced in moderate yields (entries 8 and 9). However, in contrast by taking full advantage of the mild reactivity of organozinc halides, the alkyl groups with labile function-
alities could also be installed into the desired structure (entries 10 and 11).

Table 1 1,4-Conjugated Alkylation of Olefin 1a with Various Organozinc Reagents

<table>
<thead>
<tr>
<th>Entry</th>
<th>Organozinc reagent</th>
<th>Equiv</th>
<th>Method</th>
<th>Time (h)</th>
<th>Product Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Et_2Zn</td>
<td>3.0</td>
<td>A</td>
<td>8</td>
<td>2aa 57 (54)</td>
</tr>
<tr>
<td>2</td>
<td>Et_2Zn</td>
<td>1.2</td>
<td>B</td>
<td>1</td>
<td>2aa 83 (82)</td>
</tr>
<tr>
<td>3</td>
<td>n-BuZn</td>
<td>3.0</td>
<td>A</td>
<td>8</td>
<td>2ab 62 (37)</td>
</tr>
<tr>
<td>4</td>
<td>(n-Bu)_2Zn</td>
<td>2.4</td>
<td>B</td>
<td>2</td>
<td>2ab 81 (56)</td>
</tr>
<tr>
<td>5</td>
<td>(n-Bu)_2ZnLi</td>
<td>3.0</td>
<td>C</td>
<td>2</td>
<td>2ab 27</td>
</tr>
<tr>
<td>6</td>
<td>(n-Hex)_2Zn</td>
<td>2.4</td>
<td>B</td>
<td>2</td>
<td>2ac 66 (61)</td>
</tr>
<tr>
<td>7</td>
<td>c-HexZn</td>
<td>2.4</td>
<td>A</td>
<td>8</td>
<td>2ad 50</td>
</tr>
<tr>
<td>8</td>
<td>(i-Pr)_2Zn</td>
<td>1.2</td>
<td>B</td>
<td>1</td>
<td>2ae 86 (62)</td>
</tr>
<tr>
<td>9</td>
<td>(i-Bu)_2Zn</td>
<td>2.4</td>
<td>B</td>
<td>2</td>
<td>2af 50</td>
</tr>
<tr>
<td>10</td>
<td>EtO_2C(CH_2)_3Zn</td>
<td>3.0</td>
<td>A</td>
<td>8</td>
<td>2ag 54</td>
</tr>
<tr>
<td>11</td>
<td>NC(CH_2)_3Zn</td>
<td>3.0</td>
<td>A</td>
<td>8</td>
<td>2ah 49</td>
</tr>
</tbody>
</table>

*Method A: in THF (0.25 M) at 0 °C. Method B: in toluene (0.125 M) at –78 °C. Method C: in THF (0.25 M) at –78 °C.
*a Yields were determined by 19F NMR spectroscopy, and the values in parentheses are isolated yields.
*b The commercially available salt-free organozinc reagents were used.
*c The 1,2-adduct was isolated as the major product in 69%.

Based on the known reactivity of organozinc reagents, Et_2Zn was chosen for the 1,4-conjugated alkylation with various types of electron-deficient olefins, and these results are shown in Table 2. Although slight modifications were required from the original condition depending on the reactivity of olefins 1, most electron-withdrawing groups (EWDs) can survive under the given reaction conditions without formation of any noticeable by-products (Table 2, entries 1–4). The olefin with a difluoromethyl (CF_2H) group also reacted smoothly to give the product in excellent yield (entry 5).

Finally, preliminary work on the possibility of diastereoselective 1,4-conjugated alkylation using trifluoromethylated alkenes with Evan’s chiral auxiliary was conducted (Scheme 2). Thus, treatment of 1f or 1g with 3.6 equivalents of Et_2Zn at –40 °C for 24 hours gave the corresponding 1,4-adducts in good yields; however, as diastereomeric mixtures in both cases. Further effort to attain higher diastereoselectivity is currently underway in our laboratory.

In summary, we have examined the simple yet practical 1,4-conjugated alkylation of fluoroalkylated electron-deficient olefins with various unreactive organozinc reagents without any additives.11 As a result, this reaction protocol can allow many labile alkyl groups to participate in 1,4-conjugated addition reaction; that is, our new methodology can compensate for the previously established 1,4-conjugated addition limited strictly to aromatic nucleophiles.

1H and 13C NMR spectra were recorded on a Bruker DRX-500 (500.13 MHz for 1H and 125.75 MHz for 13C) spectrometer on samples dissolved in CDCl_3 with Me_6Si as an internal reference. A Jeol JNM-AL400 (376.05 MHz) spectrometer was used to record 19F NMR spectra in CDCl_3 using CFCl_3 as an internal standard. IR spectra were recorded as liquid film or KBr disk with an Avitar-370DTGS spectrometer (Thermo Electron) or an FT/IR-4100 (JASCO) spectrometer. High-resolution mass spectra were taken with a JEOL JMS-700 MS spectrometer. Column chromatography was carried out on silica gel (Wako gel C-200) and TLC analysis was performed on silica gel TLC plates (Merck, Silica gel 60 F_254). All reactions were carried out under an atmosphere of argon. Anhyd THF and Et_2O were purchased from Wako Pure Chemical Industries, Ltd. n-BuLi (1.6 M hexane solution) was commercially available from Wako Pure Chemical Industries, Ltd. All chemicals were of reagent grade and, if necessary, were purified in the usual manner prior to use.

Table 2 1,4-Conjugated Alkylation of Various Fluoroalkylated Electron-Deficient Olefins 1 with Et_2Zn

<table>
<thead>
<tr>
<th>Entry</th>
<th>EWD</th>
<th>R_F</th>
<th>Et_2Zn (equiv)</th>
<th>Temp (°C)</th>
<th>Product Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1c</td>
<td>Cl(O)Ph</td>
<td>CF_3</td>
<td>1.2</td>
<td>–78</td>
<td>2aa 83 (82)</td>
</tr>
<tr>
<td>2d</td>
<td>Cl(O)NBn_2</td>
<td>CF_3</td>
<td>3.6</td>
<td>–40</td>
<td>2ba 80 (74)</td>
</tr>
<tr>
<td>3d</td>
<td>SO_2Ph</td>
<td>CF_3</td>
<td>3.6</td>
<td>–20</td>
<td>2ca 75 (68)</td>
</tr>
<tr>
<td>4d</td>
<td>P(O)(OEt)_2</td>
<td>CF_3</td>
<td>3.6</td>
<td>–20</td>
<td>2da 72 (69)</td>
</tr>
<tr>
<td>5c</td>
<td>Cl(O)Ph</td>
<td>CF_3H</td>
<td>2.4</td>
<td>–78</td>
<td>2ea 92 (85)</td>
</tr>
</tbody>
</table>

The reaction was conducted following method B of Table 1 but at different temperatures.
*b Yields were determined by 19F NMR spectroscopy, and the values in parentheses are isolated yields.
*c The reaction time was 1 h.
*d The reaction time was 24 h.

Scheme 2 Preliminary results of the conjugated addition using chiral substrates
1.4-Conjugated Alkylation of RZn to 4,4,4-Trifluoro-1-phenylbut-2-ene (1a); General Procedure for Method B
To a solution of 4,4,4-trifluoro-1-phenylbut-2-ene (1a; 50 mg, 0.25 mmol) in THF (1 mL) was added alkylzinc iodide (freshly prepared prior to the reaction from RZn and Zn dust) in THF at 0 °C. The mixture was then stirred for 8 h at 0 °C and quenched with sat. aq NH₄Cl (5 mL). The mixture was extracted with EtOAc (3 × 10 mL), and the combined organic layers were dried (Na₂SO₄). The organic solvents were removed, and the residue was purified by silica gel column chromatography to give the corresponding product.

1.4-Conjugated Alkylation of R₂Zn to 4,4,4-Trifluoro-1-phenylbut-2-ene (1a); 50 mg, 0.25 mmol in toluene (2 mL) was added a 1.0 M hexane solution of R₂Zn (0.3 mL, 1.2 equiv) [in case of in situ generation of R₂Zn; 50 mg, 0.25 mmol] to a solution of 4,4,4-trifluoro-1-phenylbut-2-ene (1a; 50 mg, 0.25 mmol) in THF (1 mL) at 0 °C. The mixture was then stirred at –78 °C, and for 1 h at –78 °C. The reaction was quenched with sat. aq NH₄Cl (10 mL), extracted with EtOAc (3 × 10 mL), and the combined organic layers were dried (Na₂SO₄). The organic solvents were removed, and the residue was purified by silica gel column chromatography to give the corresponding product.

1-Phenyl-3-trifluoromethylnonan-1-one (2ac)

HRMS: m/z calcd for C₁₂H₁₉F₃O (M + H): 230.0918; found: 230.0913.

29F NMR (CDCl₃): δ = –279.6 Hz, 128.73, 133.39, 136.52, 196.67.

IR (neat): 3063, 2931, 2860, 1745, 1692, 1598, 1582, 1450, 1421, 1364, 1280, 1240, 1217, 1186, 1154, 1109, 1050, 1019, 1002 cm⁻¹.

1H NMR (CDCl₃): δ = 1.42–1.49 (m, 1 H), 1.69–1.76 (m, 1 H), 3.01–3.13 (m, 1 H), 3.03 (dd, J = 17.2, 7.1 Hz, 1 H), 7.46–7.51 (m, 2 H), 7.57–7.61 (m, 1 H), 7.96–7.98 (m, 2 H).

13C NMR (CDCl₃): δ = 12.85, 21.73, 36.73 (q, J = 23.7 Hz), 128.51 (q, J = 282.2 Hz), 133.41, 134.49, 196.44.

13C NMR (CDCl₃): δ = –71.09 (d, J = 9.8 Hz, 3 F).

HRMS: m/z calced for C₁₂H₁₅F₃NO (M⁺): 270.1101; found: 270.1108.

1.4-Dimethyl-1-phenyl-3-trifluoromethylpentan-1-one (2af)

HRMS: m/z calcd for C₁₄H₂₂F₃O (M + H): 287.1623; found: 287.1620.

29F NMR (CDCl₃): δ = –67.40 (d, J = 9.8 Hz, 3 F).

IR (neat): 3062, 2930, 2884, 1691, 1598, 1582, 1465, 1450, 1422, 1394, 1349, 1326, 1307, 1257, 1219 cm⁻¹.

1H NMR (CDCl₃): δ = 1.49–1.59 (m, 1 H), 1.73–1.81 (m, 1 H), 2.97–3.08 (m, 2 H), 3.22–3.28 (m, 1 H), 7.45–7.51 (m, 2 H), 7.57–7.61 (m, 1 H), 7.96–7.98 (m, 2 H).

13C NMR (CDCl₃): δ = 11.25, 21.73, 36.73 (q, J = 2.5 Hz), 39.43 (q, J = 25.8 Hz), 128.03, 128.37 (q, J = 279.6 Hz), 128.73, 133.45, 136.49, 196.50.

1F NMR (CDCl₃): δ = –71.09 (d, J = 9.8 Hz, 3 F).

HRMS: m/z calced for C₁₄H₁₅F₃NO (M⁺): 270.1101; found: 270.1108.

4-Methyl-1-phenyl-3-trifluoromethylpentan-1-one (2ae)

HRMS: m/z calcd for C₁₄H₂₃F₃O (M + H): 259.1310; found: 259.1314.

29F NMR (CDCl₃): δ = –64.13 (d, J = 10.5 Hz, 3 F).

IR (neat): 3057, 2985, 2838, 1745, 1598, 1582, 1450, 1421, 1395, 1352, 1328, 1268, 1221, 1165, 1130, 1096 cm⁻¹.

1H NMR (CDCl₃): δ = 0.89 (t, J = 7.2 Hz, 3 H), 1.27–1.40 (m, 4 H), 1.42–1.49 (m, 1 H), 1.69–1.76 (m, 1 H), 3.01–3.13 (m, 1 H), 3.03 (dd, J = 17.2, 7.1 Hz, 1 H), 7.46–7.51 (m, 2 H), 7.57–7.61 (m, 1 H), 7.96–7.98 (m, 2 H).

13C NMR (CDCl₃): δ = 13.71, 22.60, 28.50 (q, J = 1.8 Hz), 28.89, 37.23 (q, J = 25.8 Hz), 38.08 (q, J = 26.1 Hz), 128.02, 128.70, 128.37 (q, J = 279.6 Hz), 133.41, 134.49, 196.44.

1F NMR (CDCl₃): δ = –71.32 (d, J = 9.8 Hz, 3 F).

HRMS: m/z calced for C₁₄H₁₅F₃NO (M + H): 259.1310; found: 259.1314.

Ethyl 7-Oxa-7-phenyl-5-trifluoromethylheptanoate (2ag)

Method B; the pure product was isolated as a white solid in very low yield; mp 39–40 °C.

IR (KBr): 2961, 2880, 1684, 1598, 1478, 1451, 1373, 1355, 1289, 1265, 1202, 1147, 1096, 1074, 1028 cm⁻¹.

1H NMR (CDCl₃): δ = 1.06 (s, 9 H), 3.02 (dd, J = 18.1, 3.9, 10.0 Hz, 1 H), 3.13–3.21 (ddq, J = 3.9, 6.1, 10.5 Hz, 1 H), 3.25 (dd, J = 18.1, 6.1 Hz, 1 H), 7.46–7.51 (m, 2 H), 7.57–7.61 (m, 1 H), 7.96–7.99 (m, 2 H).

13C NMR (CDCl₃): δ = 28.26, 32.39, 34.89 (q, J = 2.8 Hz), 46.09 (q, J = 23.7 Hz), 128.51 (q, J = 282.2 Hz), 128.07, 128.70, 133.36, 136.49, 196.59.

19F NMR (CDCl₃): δ = –64.13 (d, J = 10.5 Hz, 3 F).

HRMS: m/z calced for C₁₄H₁₃F₃O₃ (M + H): 259.1310; found: 259.1314.

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.
N,N-Dibenzy1-3-trifluoromethylpentanamide (2ba)

Method B; yield: 65 mg (0.19 mmol, 74%); yellow oil.

IR (neat): 3088, 3065, 3031, 2970, 2939, 2883, 1744, 1651, 1606, 1586, 1496, 1435, 1385, 1317, 1257 cm⁻¹.

1H NMR (CDCl₃); δ = 1.01 (t, J = 7.5 Hz, 3 H), 1.21–1.29 (m, 1 H), 1.35–1.40 (m, 1 H), 2.43 (dd, J = 16.5, 7.3 Hz, 1 H), 2.71 (dd, J = 16.5, 4.8 Hz, 1 H), 2.90–3.10 (m, 1 H), 4.44 (d, J = 17.2 Hz, 1 H), 4.502 (d, J = 14.6 Hz, 1 H), 4.505 (d, J = 17.2 Hz, 1 H), 4.80 (d, J = 14.6 Hz, 1 H), 7.10–7.42 (m, 10 H).

13C NMR (CDCl₃); δ = 11.25, 21.70, 31.48, 40.66 (q, J = 25.6 Hz), 48.69, 49.77, 126.18, 127.47 (q, J = 292 Hz), 127.51, 127.74, 128.24, 128.63, 129.04, 136.03, 137.05, 170.46.

19F NMR (CDCl₃); δ = −70.93 (d, J = 7.6 Hz, 3 F).

HRMS: m/z calcd for C₂₀H₂₅F₃NO (M + H): 350.1732; found: 350.1728.

2-Trifluoromethylbutyl Phenyl Sulfone (2ca)

Method B; yield: 45 mg (0.17 mmol, 68%); yellow oil.

IR (neat): 3086, 2977, 2945, 2889, 1586, 1465, 1448, 1414, 1383, 1326, 1253, 1151, 1084, 1044, 1025 cm⁻¹.

1H NMR (CDCl₃); δ = 1.03 (dt, J = 7.5, 0.81 Hz, 3 H), 1.78–1.88 (m, 2 H), 2.69–2.80 (m, 1 H), 3.14 (dd, J = 14.6, 8.3 Hz, 1 H), 3.33 (dd, J = 14.6, 2.9 Hz, 1 H), 7.59–7.62 (m, 2 H), 7.68–7.72 (m, 1 H), 7.93–7.95 (m, 2 H).

13C NMR (CDCl₃); δ = 10.54, 21.32, 39.52 (q, J = 27.3 Hz), 54.00, 126.81 (q, J = 280.8 Hz), 127.93, 129.52, 134.18, 139.02.

19F NMR (CDCl₃); δ = −70.61 (d, J = 7.6 Hz, 3 F).

HRMS: m/z calcd for C₁₄H₁₄F₃OS (M + H): 267.0667; found: 267.0661.

Diethyl [2-(Trifluoromethyl)butyl]phosphonate (2da)

Method B; yield: 45 mg (0.17 mmol, 68%); yellow oil.

1H NMR (CDCl₃); δ = 1.02 (t, J = 7.4 Hz, 3 H), 1.33 (t, J = 7.0 Hz, 6 H), 1.70–1.90 (m, 3 H), 2.03 (dd, J = 21.2, 15.7, 3.4 Hz, 1 H), 2.40–2.55 (m, 1 H), 4.04–4.17 (m, 4 H).

13C NMR (CDCl₃); δ = 10.68, 16.31, 16.41, 21.60–21.75 (m, 1 C), 24.00 (dq, J = 146.2, 2.7 Hz), 39.32 (qd, J = 26.5, 2.7 Hz), 61.86 (d, J = 6.5 Hz, 61.95 (d, J = 6.9 Hz, 127.77 (qd, J = 279.2, 18.5 Hz).

19F NMR (CDCl₃); δ = −67.40 (d, J = 9.8 Hz, 3 F).

HRMS: m/z calcd for C₁₃H₁₃F₃O₂P (M + H): 263.1024; found: 263.1029.

3-Difluoromethyl-1-phenylpentan-1-one (2ea)

Method B; yield: 49 mg (0.21 mmol, 85%); yellow oil.

IR (neat) 3062, 2966, 2940, 2882, 1688, 1598, 1581, 1463, 1449, 1380, 1359, 1320, 1260 cm⁻¹.

1H NMR (CDCl₃); δ = 0.99 (t, J = 7.5 Hz, 3 H), 1.49 (ddg, J = 14.7, 7.3, 7.3 Hz, 1 H), 1.65 (ddg, J = 14.7, 7.4, 7.4 Hz, 1 H), 2.53–2.65 (m, 1 H), 2.99 (dd, J = 17.8, 6.9 Hz, 1 H), 3.21 (dd, J = 17.8, 5.6 Hz, 1 H), 5.94 (dd, J = 57.5, 2.9 Hz, 1 H), 7.45–7.49 (m, 2 H), 7.54–7.60 (m, 1 H), 7.95–8.00 (m, 2 H).

13C NMR (CDCl₃); δ = 11.33, 21.08 (dd, J = 5.8, 3.5 Hz, 35.89 (t, J = 4.4 Hz), 39.39 (t, J = 19.1 Hz), 117.90 (t, J = 2418 Hz), 127.99, 128.63, 133.25, 136.75, 197.99.

19F NMR (CDCl₃); δ = −123.81 (dd, J = 275.3, 56.5, 14.1 Hz, 1 F), −125.17 (dd, J = 275.3, 56.5, 19.8 Hz, 1 F).

HRMS: m/z calcd for C₁₃H₁₃F₃O (M + H): 213.1090; found: 213.1084.

(5)-3-[3-(Trifluoromethyl)pentanoyl]-4-phenyloxazolidin-2-one (2fa)

Method B.
13C NMR (CDCl3): δ = 11.24, 21.54 (q, J = 2.0 Hz), 34.04 (q, J = 2.5 Hz), 37.69, 39.78 (q, J = 26.2 Hz), 55.27, 66.33, 127.42, 127.94 (q, J = 279.8 Hz), 129.00, 129.35, 134.98, 153.31, 170.48.

19F NMR (CDCl3): δ = –70.17 (d, J = 9.8 Hz, 3 F).

HRMS: m/z calculated for C16H19F3NO3 (M + H): 330.1317; found: 330.1325.

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synthesis.

References


(8) The alkylzinc halides, RZnI, were prepared according to the reported procedure; see ref. 4b.

(9) The prepared dialkylzinc reagents were used without the removal of LiCl. For the detailed preparation procedure, see the experimental section.

(10) The lithium zincate, (n-Bu)3ZnLi, was prepared by mixing 3 equiv of n-BuLi (1.6 M hexane solution) and 1 equiv of ZnCl2 (1.0 M, Et2O solution) at 0 °C for 30 min.

(11) The reactivity of dialkylzinc reagents is: salt-free R2Zn > in situ generated R2Zn.

(12) The control experiments were conducted as follows. The 1,4-conjugated additions to (E)-1-phenylbut-2-en-1-one or chalcone with Et2Zn were attempted under the same conditions as given in Table 1, entry 2; however, a quantitative amount of the starting alkene was recovered in both cases (methods A and B).