Decarbonylation via Aldehydic C–H Bond Cleavage by Cationic Iridium Catalyst

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Abstract We report the decarbonylation of aldehydes via aldehydic C–H bond cleavage catalyzed by cationic iridium/bisphosphine catalyst. The reaction proceeds under relatively mild reaction conditions, providing the corresponding hydrocarbon products in moderate to high yields. In addition, this cationic iridium catalyst system can be applied to asymmetric ketone hydroacylation reaction.

Keywords decarbonylation, cationic iridium, benzaldehyde, C–C bond cleavage, asymmetric acylation, ketone

Transition metal-catalyzed carbonylation using inexpensive carbon monoxide (CO gas) is one of the most common industrial processes to synthesize the bulk and fine chemicals.1 Similarly, transition metal-catalyzed decarbonylation of carbonyl compounds is the fundamental reaction in synthetic chemistry because it can be applied to beneficial C–C bond formations such as cross-coupling reactions.2–4 In addition, decarbonylation reaction is also regarded as an efficient method for attractive carbon–carbon bond cleavage.5 Among them, decarbonylation of aldehyde is most basic decarbonylation reaction and have been known for a long time. The stoichiometric rhodium-mediated simple decarbonylation for aldehydes have first developed by Tsuji and Ohno in 1965.6 Decarbonylation of aldehydes was well-established, and was realized by use of various transition metal catalysts.7a,b, 7–12 In 2008, Tsuji and co-workers reported that aromatic and aliphatic aldehydes react in the presence of a neutral iridium catalyst to give corresponding decarbonylated products in good yield (Scheme1 (a)).13 A wide range of functional group were tolerant for this reaction. Recently, earth-abundant nickel-catalyzed decarbonylation of aldehydes was also developed.11 More recently, cobalt-mediated decarbonylation of aldehydes has been reported by Tonzetich.12 Although there are many active catalyst systems for decarbonylation, a common feature of most of these reactions is to use neutral metal complex. However, it is known that cationic complex promotes the decarbonylation by decreasing π-backdonation from metal center to an antibonding orbital of CO.7a As a new entry for catalytic decarbonylation of aldehydes, here we describe the development of a cationic iridium-catalyzed decarbonylation reaction of aldehydes with high substituent

Table 1 Screening of Reaction Conditions for Catalytic Decarbonylation

<table>
<thead>
<tr>
<th>entry</th>
<th>cat.</th>
<th>ligand</th>
<th>solvent</th>
<th>yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ir(cod)(BARF)2</td>
<td>rac-binap</td>
<td>Toluene</td>
<td>68</td>
</tr>
<tr>
<td>2</td>
<td>Ir(cod)(BF3)2</td>
<td>rac-binap</td>
<td>Toluene</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>Ir(cod)Cl</td>
<td>rac-binap</td>
<td>Toluene</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>Ir(cod)(BARF)2</td>
<td>[R]-tol-binap</td>
<td>Toluene</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>Ir(cod)(BARF)2</td>
<td>[R]-xyl-binap</td>
<td>Toluene</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>Ir(cod)(BARF)2</td>
<td>[R]-segphos</td>
<td>Toluene</td>
<td>61</td>
</tr>
<tr>
<td>7</td>
<td>Ir(cod)(BARF)2</td>
<td>dpff</td>
<td>Toluene</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>Ir(cod)(BARF)2</td>
<td>PPh3</td>
<td>Toluene</td>
<td>4</td>
</tr>
</tbody>
</table>

Scheme 1 Iridium-catalyzed Decarbonylation of Aldehydes

(a) Report by Tsuji et al. (2008)

(b) This work

R = Ar, alkyl
compatibility (Scheme 1(b)). Initially, we choose 2-ethoxybenzaldehyde (1a) as a model substrate and attempted the decarbonylation in the presence of [Ir(cod)]([BArF4]) (5 mol%) and rac-BINAP (5.5 mol%) in toluene at 135 °C. Note that we previously confirmed that the chirality of ligand does not affect the reactivity. Under these conditions, the decarbonylation proceeded to give the product 2a in 68% yield (Table 1, entry 1).

Table 2 Cationic Iridium-Catalyzed Decarbonylation of Aldehydes

<table>
<thead>
<tr>
<th>entry</th>
<th>aldehyde</th>
<th>product (2a, 2b, 2e) yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OEt</td>
<td>OEt 2a</td>
</tr>
<tr>
<td>2</td>
<td>OMe</td>
<td>OMe 2b</td>
</tr>
<tr>
<td>3</td>
<td>MeO2C</td>
<td>CO2Me 2e</td>
</tr>
<tr>
<td>4</td>
<td>MeNO2</td>
<td>NHAc 2g</td>
</tr>
<tr>
<td>5</td>
<td>APhN</td>
<td>NHAc 2g</td>
</tr>
<tr>
<td>6</td>
<td>EliNOC</td>
<td>CONMe2 2h</td>
</tr>
<tr>
<td>7</td>
<td>Ac</td>
<td>Ac 2j</td>
</tr>
<tr>
<td>8</td>
<td>EiNOC</td>
<td>CONEi 2i</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
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</tr>
<tr>
<td>14</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td></td>
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</table>

Reaction conditions: aldehyde 1 (0.25 mmol), iridium 5 (5 mol%), and (R)-Xyl-BINAP 5.5 mol% in THF, 135 °C, 24 h.

The mechanism of the decarbonylation has been already well-established as illustrated in Scheme 2. Lastly, we have also briefly investigated the application using reactive species for decarbonylation such as acyliridium–hydride intermediate generated in situ by aldehydic C–H bond cleavage. Because the asymmetric hydroacylation of ketones catalyzed by rhodium13a-c or cobalt13c complex was previously reported, we presumed that the asymmetric hydroacylation occurs via acyliridium–hydride complex. In fact, cationic iridium-catalyzed atom-economical asymmetric hydroacylation of benzaldehyde 1j proceeded to give the corresponding chiral phthalide 3 in 57% conversion with good enantioselectivity (70%ee) (Scheme 3). The cationic property of iridium complex was beneficial for the use in an asymmetric hydroacylation, and the neutral complex.
did not catalyze the reaction. To our knowledge, this reaction represents the first example of iridium-catalyzed asymmetric hydroacylation of ketone via aldehydeic C–H bond cleavage.\(^{14}\)


In summary, we have reported a new efficient system for the decarbonylation via aldehydic C–H bond cleavage using a cationic iridium/bidentate phosphine catalyst.\(^{15}\) The cationic iridium catalyst system is synthetically useful, as demonstrated by asymmetric hydroacylation of ketone providing convenient chiral five-membered lactones.\(^{16}\) We are currently working to develop new cationic iridium-catalyzed synthetic methods via C–H bond cleavage.

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**Supporting Information**

YES (this text will be updated with links prior to publication)

**Primary Data**

NO (this text will be deleted prior to publication)

**References and Notes**


Representative general procedure of decarbonylation – preparation of benzyl phenyl ether (2b)

To an oven-dried sealed tube, [Ir(cod)2(BArF4)] (0.0125 mmol, 5 mol%) and (R)-xyl-binap (0.0138 mmol, 5.5 mol%) and dry THF (1.0 mL) were added under N2 atmosphere. The mixture was stirred at room temperature for 30 min, followed by the addition of benzaldehyde 1b (0.25 mmol). The reaction mixture was then heated at 135 °C. After being stirred for 24 h, the mixture was purified with silica gel column chromatography (eluent: Hexane only) to afford pure decarbonylation product 2b (35% yield).

1H NMR (400 MHz, CDCl3) δ 7.27–7.45 (m, 7H), 6.96-7.00 (m, 3H), 5.07 (s, 3H).

General procedure of asymmetric hydroacylation – preparation of 3-methylisobenzofuran-1(3H)-one (3)

To an oven-dried 2-neck flask with condenser, [Ir(cod)2(BArF4)] (0.0125 mmol, 5 mol%) and (R)-Xyl-BINAP (0.0138 mmol, 5.5 mol%) and dry THF (1.0 mL) were added under N2 atmosphere. The solution was stirred at room temperature for 30 min, followed by the addition of benzaldehyde 1a (0.25 mmol). The reaction mixture was then heated at 90 °C. After being stirred for 48 h, lactone (3) was confirmed by 1H-NMR and conversion was determined by 1H-NMR integration comparing to substrate peak.

1H NMR (400 MHz, CDCl3) δ 7.91 (d, J = 7.6 Hz, 1H), 7.68 (td, J = 7.6, 1.2 Hz, 1H), 7.53 (t, J = 7.6 Hz, 1H), 7.44 (dd, J = 8.0, 1.2 Hz, 1H), 5.57 (q, J = 6.8 Hz, 1H), 1.65 (d, J = 6.4 Hz, 1H).