Herein, we report a ring-opening 1,3-arylboration of arylcyclopropanes using BCl₃ in the presence of arene nucleophiles. Formal 1,3-oxo arylation and 1,3-amino arylation of the arylcyclopropane via one-pot derivatization of the installed boron group were also achieved.

We began our study on the ring-opening 1,3-arylboration of cyclopropanes using cyclopropylbenzene (1a) and toluene (10 equiv.) as a model reaction (Table 1). The use of BCl₃ in CH₂Cl₂ at room temperature was not effective, and allylbenzene was mainly obtained (entry 1). Allylbenzene is considered to be produced through a formation of benzylic cation via C–C bond cleavage by BCl₃, a formation of homobenzyl cation by 1,2-hydride migration, and subsequent dissociation of the boron group. On the other hand, when the reaction was carried out at −30 °C, the formation of allylbenzene was suppressed, and the desired 1,3-arylborated product 2a was isolated in 11% yield *via* in situ formations of the pinacol boronate ester by treatment with pinacol and triethylamine (entry 2). Encouraged by these results, we further investigated different borane reagents for the reaction. When BBr₃ was used, 2a was not produced. Instead,
allylbenzene was formed even at low temperature (entry 3). The use of B-bromocatecholborane or BF$_3$·OEt$_2$ was also not effective (entries 4 and 5). From these results, BCl$_3$ was found to be an optimal reagent. Then, we investigated the reaction time and reaction temperature in detail. It was found that extending the reaction time to 48 hours improves the yield to 45% (entry 6). On the other hand, further studies on the reaction temperature did not improve the yield (entries 7 and 8). Finally, it was found that the amount of BCl$_3$ used is essential for improving the efficiency of the reaction (entry 9 and 10), and when five equivalent of BCl$_3$ was used, compound 2a was obtained in 81% yield. Regarding the amount of nucleophile, the yield was decreased when the amount of toluene was reduced to 5 equivalent (entry 11). Therefore, the optimal reaction conditions found for the 1,3-arylboration of arylcyclopropane involved treatment with BCl$_3$ (5 equiv.) in CH$_2$Cl$_2$ in the presence of toluene (10 equiv.).

With optimized conditions in hand, we investigated the substrate scope of this transformation (Table 2). p-tBu cyclopropylbenzene and 2-cyclopropylnaphthalene gave 2b and 2c in moderate to excellent yields. In contrast, p-PhO cyclopropylbenzene gave only a 16% yield, showing that the oxygen atom in the substrate could not be preferable for the reaction, probably due to the high affinity of oxygen atom toward BCl$_3$. On the other hand, bromo or chloro substituted aryl cyclopropanes worked well (2e, 2f). We also studied the scope of nucleophiles with 1a. The reactions using benzene were first examined, but it was found that benzene gave a complex mixture (not shown in table). It is probably because the nucleophilicity of cyclopropylbenzene was relatively higher than that of benzene. Therefore, we focused on a series of alkyl-substituted benzenes. p-Xylene, mesitylene, p-Et benzene, p-tBu benzene, and biphenyl provided the corresponding products 2g–2k in good yield. The reaction with 1,2,3,4-tetrahydronaphthalene also proceeded to give 2l regioselectively.

One-pot derivatization using the installed boron group was also studied in addition to converting it into pinacol boronic esters for isolation. As shown in Scheme 2, oxidative workup of the C–B bond using hydrogen peroxide under basic conditions readily furnished alcohol 4 in excellent yield from 1a. Also, the treatment of 3 with benzyl azide gave secondary amine 5 in 64% yield.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Reagent (equiv.)</th>
<th>Temp. (°C)</th>
<th>Time (h)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1$^b$</td>
<td>BCl$_3$ (1.1)</td>
<td>rt</td>
<td>2</td>
<td>Trace</td>
</tr>
<tr>
<td>2</td>
<td>BCl$_3$ (1.1)</td>
<td>−30</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>BBr$_3$ (1.1)</td>
<td>−30</td>
<td>10</td>
<td>N.D.$^c$</td>
</tr>
<tr>
<td>4$^b$</td>
<td>B-Bromocatecholborane (1.1)</td>
<td>−30</td>
<td>10</td>
<td>N.R.$^d$</td>
</tr>
<tr>
<td>5$^b$</td>
<td>BF$_3$·OEt$_2$ (1.1)</td>
<td>−30</td>
<td>10</td>
<td>N.R.$^d$</td>
</tr>
<tr>
<td>6</td>
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<td>48</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
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<tr>
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<td>66</td>
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<tr>
<td>10</td>
<td>BCl$_3$ (5.0)</td>
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<td>81</td>
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<tr>
<td>11$^e$</td>
<td>BCl$_3$ (5.0)</td>
<td>−30</td>
<td>48</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 1 Study of reaction conditions

Table 2 Scope of aryl cyclopropanes

$^a$ p : o = 20 : 1. $^b$ Pinacol and NEt$_3$ were not treated. $^c$ Not detected. $^d$ No reaction. $^e$ Toluene (5 equiv.).

Scheme 2 Formal 1,3-oxy arylation and 1,3-amino arylation. Conditions for 4: 1a (0.20 mmol), BCl$_3$ (1.0 mmol), CH$_2$Cl$_2$ (1.2 mL), −30 °C, 48 h then 2 M NaOH/30% H$_2$O$_2$ (1.5 mL, 1 : 1 v/v), 0 °C, 3 h; conditions for 5: 1a (0.20 mmol), BCl$_3$ (1.0 mmol), toluene (2.0 mmol), CH$_2$Cl$_2$ (1.2 mL), −30 °C, 48 h, then evaporation, CH$_2$Cl$_2$ (0.4 mmol), CH$_2$Cl$_2$ (1.5 mL), rt, 2 h.
yield. It should be noted that 3,3-diaryl-propylamine is a structural motif found in some pharmaceuticals such as fendiline. These one-pot transformations can be considered as a formal 1,3-oxy arylation or 1,3-amino arylation of the arylcyclopropane, which has not been reported so far.

A possible reaction mechanism was depicted in Scheme 3. Given the reported paper, this ring-opening 1,3-arylboronation is suggested to proceed in a stepwise manner. That is, the treatment of BCl3 to aryl cyclopropane could generate a zwitterionic intermediate i. The following nucleophilic addition of an arene to benzylic cation could give intermediate ii, which is transformed to pinacol borate by the reaction with pinacol and triethylamine.

In summary, we have developed a method for the 1,3-arylboronation of arylcyclopropanes to provide 3,3-diaryl-propyl boronic esters for the first time. It was found that BCl3 was optimal as the boron source in the presence of arene nucleophiles. The formal 1,3-oxy arylation and 1,3-amino arylation of the arylcyclopropane via one-pot derivatization of the installed boron group were also achieved. A full account of these studies will be reported in due course.

Conflicts of interest

There are no conflicts to declare.

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