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Asymmetric Synthesis of 1-Heteroaryl-1-Arylalkyl Tertiary Alcohols and 1-Pyridyl-1-Arylethanes by Lithiation-Borylation Methodology

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ABSTRACT

The synthesis of highly enantioenriched α-heterocyclic tertiary alcohols has been achieved via lithiation-borylation of a configurationally-stable lithiated carbamate and heterocyclic pinacol boronic esters followed by oxidation. Protodeboronation of the α-heterocyclic tertiary boronic esters using TBAF.3H2O or CsF gave highly enantioenriched 1-pyridyl-1-arylethanes in high er.

There are a number of methods available for the synthesis of highly enantioenriched tertiary alcohols, most of them involving addition of an organometallic reagent to a ketone catalysed by a chiral metal/ligand complex. However, this method is scarcely reported for pyridyl ketones, which may be due to intrinsic problems of competing coordination of the heteroatom to the metal complex, or to other unwanted side reactions. Due to the prevalence of heterocyclic tertiary alcohols in bioactive molecules, we have sought to address this issue by application of our lithiation – borylation methodology, which provides an alternative route to highly enantioenriched tertiary alcohols. In this process, a benzylic carbamate derived from an enantioenriched secondary alcohol is deprotonated and reacts with a boronic ester to give an intermediate boronate complex; subsequent stereospecific 1,2-metallate rearrangement and oxidation thereafter leads to highly enantioenriched tertiary alcohols (Scheme 1). Herein we report the application of this methodology to the synthesis of α-heterocyclic tertiary alcohols.

Scheme 1. Proposed lithiation-borylation route to heterocyclic tertiary alcohols

We began our studies by preparation of the required starting materials; the enantioenriched carbamate 1 was synthesized by enzymatic resolution of racemic phenylethanol followed by carbamoylation with N,N-
diisopropylcarbamyl chloride, giving the carbamate in >99:1 er. The boronic esters were synthesized by condensation of the appropriate boronic acid with pinacol.

Initial attempts to homologate 3-pyridyl pinacol boronic ester proved unsuccessful, which we attributed to its poor solubility in compatible reaction solvents (Et₂O, toluene, hexane, TBME). However, we found that the inclusion of a halogen substituent on the pyridyl ring greatly aided solubility. We subjected boronic ester 2a to lithiation–borylation using MgBr₂/MeOH as an additive to enhance er (method A). Pleasingly, the tertiary boronic ester 3a was formed in 50% yield (Scheme 2). Subsequent oxidation of 3a with NaOH/H₂O₂ gave the desired tertiary alcohol 4a in 76% yield and 98:2 er. When this was carried out without isolation of the intermediate tertiary boronic ester, 4a was isolated in 45% yield.

**Scheme 2.** Scope of the lithiation–borylation methodology

![Scheme 2](image)

Conditions A: 2 added to Li-1 as a 1 M Et₂O or 0.5 M PhMe solution, subsequent addition of MgBr₂/MeOH prior to warming to rt. B: 2 added to Li-1 as a 1 M Et₂O or 0.5 M PhMe solution (no MgBr₂/MeOH).

Encouraged by this result, we sought to establish the scope of the lithiation–borylation method using a range of commercially available heterocyclic boronic acids from which we could synthesize the corresponding boronic esters. Continuing the investigation of ortho-substituted boronic esters, we utilized the 2-fluoro- and 2-methoxy-substituted pyridyl boronic esters 2b and 2c, and isolated the tertiary boronic esters 3b and 3c in excellent yield. Oxidation of both tertiary boronic esters 3b and 3c gave the corresponding tertiary alcohols 4b and 4c in high yield and enantiomeric ratio. The additional ortho-substituents on the pyridyl ring appear to be well tolerated without detriment to the yield or enantioselectivity of the lithiation–borylation.

Having established that the lithiation–borylation reaction could be applied to pyridyl boronic esters, we explored reaction conditions with and without MgBr₂/MeOH (conditions A and B respectively). In the case of 2-substituted-3-boryl pyridines (4a-c), higher er and yield was achieved with the use of MgBr₂/MeOH (conditions A), especially in the case of 4c. This reflects an element of reversibility in the ate complex formation, arising from the increased steric hindrance of the ortho-substituted boronic esters. Upon warming the reaction to room temperature, the lithiated carbamate so generated becomes configurationally labile, begins to racemize, and subsequent recombination leads to the tertiary boronic ester with a reduced er (Scheme 3). In the presence of MgBr₂/MeOH, the extent of reversibility is reduced relative to 1,2-migration, and any lithiated carbamate that is released is immediately trapped by MeOH, leading to an increased er. Indeed, these conditions give the highest possible er in the lithiation–borylation since they are kinetically controlled.

**Scheme 3.** The beneficial effect of MgBr₂/MeOH upon lithiation–borylation with sterically demanding substrates

![Scheme 3](image)
Moving to 2-halo-5-pyridyl boronic esters (4d/4e) resulted in a dramatic decrease in yield due to competing protodeboronation of the intermediate tertiary boronic esters using MgBr₂/MeOH (method A). We therefore explored alternative conditions and found that using a PhMe/Et₂O solvent system without the use of MgBr₂/MeOH (Method B) led to increased yields of the tertiary alcohols without detriment to the er. 4-Pyridyl boronic esters could also be used but were less successful, giving either low yields or enantioselectivities for 4f–4h. In the case of 4f using method B, only the protodeboronated product 5f was isolated (with very low enantiomeric enrichment). The low yield of 4g can also be attributed to the propensity of the tertiary boronic ester to protodeboronate. In fact, using method A, protodeboronation was so extensive that none of the desired alcohol could be isolated, and using method B resulted in a low yield of 4g. However, the tertiary alcohol 4h was isolated in good yield using method A and excellent yield using method B. The low enantioselectivity observed for 4h even with the addition of MgBr₂/MeOH was a surprise. In fact this is the first and only example where essentially complete retention of stereochemistry in the trapping of the lithiated carbamate by a boronic ester is not observed. This may be due to the reduced ability of the boronic ester to coordinate to lithium due to the strong electron-withdrawing groups on the heteroaromatic ring, since in the absence of coordination (e.g., with boranes), the reaction occurs with complete inversion of stereochemistry (Scheme 4).

**Scheme 4.** The effect of precomplexation upon electrophilic attack of an organoborane upon Li-I

The absolute stereochemistry of the tertiary boronic ester 3a was determined by X-ray crystallography, and showed that the lithiation-borylation reaction had occurred with the expected retention of stereochemistry (figure 1). Other classes of heterocycles were used successfully. The dihydropiperidine boronic ester 2k and indole boronic ester 2l led to successful isolation of the corresponding tertiary alcohols 4k and 4l in good yield and very high er.

Although unsubstituted pyridyl boronic esters could not be employed in this process, due to their poor solubility, tertiary alcohol 4 could nevertheless be accessed indirectly, following reductive removal of the halogen substituent from the tertiary alcohol 4d after lithiation-borylation and oxidation, and gave tertiary alcohol 4 in 67% yield (Scheme 5).

**Scheme 5.** Preparation of tertiary alcohol 4d

Following our success at lithiation–borylation with these substrates, we briefly investigated the application of protodeboronation in this context. Since 1,1-diarylalkanes are privileged pharmacophores in medicinal chemistry, we were keen to examine whether the heterocyclic analogues could be prepared by protodeboronation of the intermediate tertiary boronic esters. We previously reported two sets of conditions for protodeboronation of tertiary boronic esters: CsF/H₂O for diarylalkyl boronic esters and TBAF·3H₂O for arylalkyl boronic esters. We initially tested the former conditions and found that...
the boronic ester 3b underwent clean and rapid protodeboronation with complete retention of stereochemistry (Table 1, entry 2). However, the protodeboronation of tertiary boronic esters 3a and 3c (entries 1 and 3) were found to be very slow with CsF. Application of TBAF.3H₂O greatly reduced reaction times and led to the aryl-heteroaryl-alkyl methines 5a and 5c in high yield.

<table>
<thead>
<tr>
<th>entry</th>
<th>Het</th>
<th>yield</th>
<th>conditions</th>
<th>yield (er)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3a</td>
<td>50</td>
<td>TBAF₂</td>
<td>92 (94:6)</td>
</tr>
<tr>
<td>2</td>
<td>3b</td>
<td>78</td>
<td>CsF</td>
<td>92 (&gt;99:1)</td>
</tr>
<tr>
<td>3</td>
<td>3c</td>
<td>85</td>
<td>TBAF₂</td>
<td>88 (99:1)</td>
</tr>
</tbody>
</table>

* TBAF.3H₂O (1.5 equiv), toluene, -20 °C to rt, 2 h. **CsF** (1.5 equiv), CH₂Cl₂, rt, 2 h.

In conclusion, we have successfully extended our lithiation-borylation methodology to encompass a range of heterocyclic boronic esters. From easily accessible starting materials, we have synthesized several α-heterocyclic tertiary alcohols in good-to-excellent yield with excellent enantioselectivity. However, depending on the nature of the heterocycle, some intermediate tertiary boronic esters are prone to protodeboronation and so can lead to reduced yields. In addition, we have combined the lithiation – borylation methodology with our previously developed protodeboronation conditions to synthesize highly enantioenriched 1-pyridyl-1-arylethanes.

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**Supporting Information Available** Experimental procedures, characterization data, NMR spectra and CIF of compound 3a. This material is available free of charge via the Internet at http://pubs.acs.org.

