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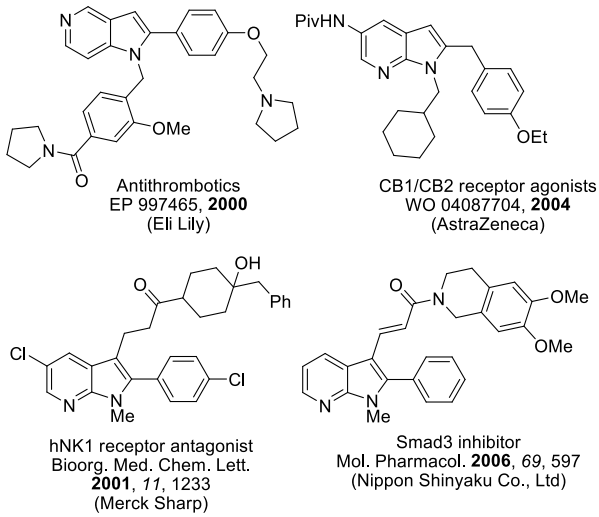
## ABSTRACT


**A new method for the synthesis of 5-azaindole derivatives is reported. A [3+2] dipolar cycloaddition between nitriles and a 3,4-cyclopropanopiperidine followed by $SeO_2$ oxidation affords the target compounds in moderate to excellent yields. The divergent nature and cost effectiveness of this method makes it very suitable for combinatorial applications in the pharmaceutical industry.**

Considerable attention has been directed to the development of azaindole based pharmaceuticals as indole isosteres due to their role in patent evasion, often enhanced solubility and perhaps superior bioavailability.[1] These efforts have resulted in the discovery of many active drug candidates (see Figure 1 for representative examples).[2] Despite the promising potential of these hetercycles, they remain largely underexplored, in part due to the limited synthetic methods to prepare and functionalize the azaindole nucleus.

**Figure 1.** Examples of pharmacologically active azaindoles

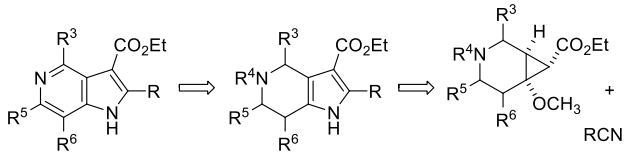



(1) For recent reviews and references cited therein: (a) Popowyez, F.; Mérour, J.-Y.; Joseph, B. J. *Tetrahedron* **2007**, *63*, 8689–8707. (b) Song, J. J.; Reeves, J. T.; Gallou, F.; Tan, Z.; Yee, N. K.; Senanayake, C. H. *Chem. Soc. Rev*. **2007**, *36*, 1120–1132. (c) Popowycz, F.; Routier, S.; Joseph, B.; Mérour, J.-Y. *Tetrahedron* **2007**, *63*, 1031–1064.

(2) (a) Bastian, J. A.; Fisher, M. J.; Harper, R. W.; Lin, H-S.; Mccowan, J. R.; Sall, D. J.; Smith, G. F.; Takeuchi, K.; Wiley, M. R.; Zhang, M. Eur. Pat. Appl. EP 997465, 2000; *Chem. Abstr*. **2000**, *132*, 293756. (b) Wei, Z.; Dolaine, R.; Walpole, C.; Yang, H.; Appl. Int. WO 2004087704, 2004; *Chem. Abstr*. **2004**. *141*, 332183. (c) Cooper, L. C.; Chicchi, G. G.; Dinnell, K.; Elliott, J. M.; Hollingworth, G. J.; Kurtz, M. M.; Locker, K. L.; Morrison, D.; Shaw, D. E.; Tsao, K.-L.; Watt, A. P.; Williams, A. R.; Swain, C. J. *Bioorg. Med. Chem. Lett*. **2001**, *11*, 1233–1036. (d) Jinnin, M.; Ihn, H.; Tamaki, K. *Mol. Pharmacol*. **2006**, *69*, 597–607.

While there are many synthetic methods available for the preparation of substituted indoles,[3] only a few have been developed for the preparation of azaindoles. Some of the classic methods either do not work or are inefficient.[1] The alternative methods generally rely on highly functionalized pyridine substrates, which are expensive or require multistep syntheses to prepare.[4] Additionally, C2 and C3 substituted 5-azaindoles are notoriously difficult to access as they often depend on multistep approaches involving highly functionalized pyridines, or strong bases to lithiate the 5-azaindole itself followed by electrophile trapping.[5] The formal dipolar cycloaddition reaction developed by our group[6] has been shown to be useful for the preparation of pyrroles,[7] bipyrroles,[8] indolizines[9] and indole alkaloid natural products.[10] Herein, we report a two step sequence for the synthesis of 5-azaindoles by oxidation of a tetrahydro-1*H*-pyrrolo[3,2-c]pyridine intermediate obtained through a cycloaddition reaction between nitriles and a 3,4-cyclopropanopiperidine (Scheme 1).[11]

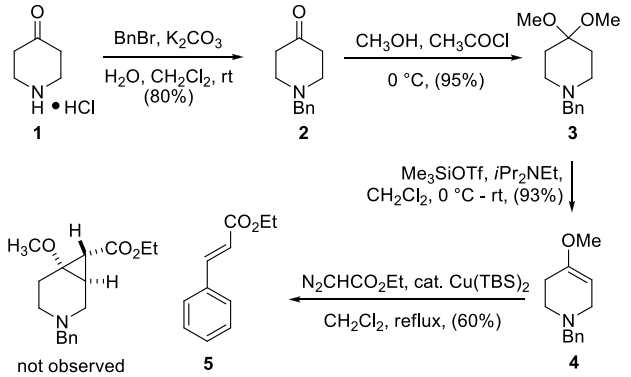
**Scheme 1**. Retrosynthetic analysis



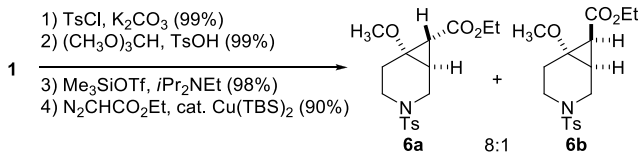

This strategy allows access to a wide variety of C2 functionalized azaindoles simply by varying the starting nitrile.

The synthesis of the cyclopropanopiperidine began with benzyl protection of 4-piperidone **1** followed by acetalization in acidic methanol (Scheme 2).[12] Then the resulting acetal **3** was converted to enol ether **4** under standard conditions;[13] however, when **4** was subjected to cyclopropanation with ethyl diazoacetate in presence of $Cu(TBS)_2$,[14] the ethyl cinnamate **5** was obtained in 60% yield and none of the desired cyclopropane was observed. The cinnamate is likely formed by carbene insertion at the benzylic position followed by elimination. To avoid this undesired reaction a tosyl protecting group was employed (Scheme 3),[15] and cyclopropanation under the same conditions afforded the desired cyclopropane **6** in 90% yield as an inconsequential 8 : 1 mixture of *trans* to *cis* diastereomers.[16]

**Scheme 2**. Attempted synthesis of the cyclopropanopiperidine




**Scheme 3**. Access to cyclopropanopiperidines




(3) Gribble, G. W. *J. Chem. Soc., Perkin Trans*. 1, **2000**, *7*, 1045–1075.

(4) (a) Evans, G. B.; Furneaux, R. H.; Hutchison, T. L.; Kezar, H. S.; Morris, P. E., Jr.; Schramm, V. L.; Tyler, P. C. *J. Org. Chem*. **2001**, *66*, 5723–5730. (b) Zhu, J.;Wong, H.; Zhang, Z.;Yin, Z.; Meanwell, N. A.; Kadow, J. F.; Wang, T. *Tetrahedron Lett*. **2006**, *47*, 5653–5656. (c) Roy, P. J.; Dufresne, C.; Lachance, N.; Leclerc, J.-P.; Boisvert, M.; Wang, Z.; Leblanc, Y. *Synthesis* **2005**, 2751–2757. (d) Zhang, Z.; Yang, Z.; Meanwell, N. A.; Kadow, J. F.; Wang, T. *J. Org. Chem*. **2002**, *67*, 2345–2347. (e) Saab, F.; Bénéteau ,V.; Schoentgen, F.; Mérour, J.-Y.; Routier, S. *Tetrahedron*, **2010**, *66,*102–110. (f) Zheng, X.; Kerr, M. A. *Org. Lett*. **2006**, *8*, 3777–3779.

(5) (a) Fang,Y.-Q.; Yuen, J., Lautens, M. *J. Org. Chem*. **2007**, *72*, 5152-5160. (b) Roy, P.; Boisvert, M.; Leblanc, Y. *Org. Synth.* **2007**, *84*, 262–271. (c) Lefoix, M.; Daillant, J.-P.; Routier, S.; Merour, J.-Y.; Gillaizeau, I.; Coudert, G. *Synthesis* **2005**, *20*, 3581–3588. (d) Xu, L.; Lewis, I. R.; Davidsen, S. K.; Summers, J. B. *Tetrahedron Lett*. **1998**, *39*, 5159–5162. (e) Bisagni, E.; Ducrocq, C.; Civier, A. *Tetrahedron* **1976**, *32*, 1383–1390. (f) Zhang, S.; Sun, X.; Zhang, W-X.; Xi, Z. *Chem. Eur. J.* **2009**, *15*,12608–12617. (g) Shaykoon, M. S. A.; Inagaki, F.; Mukai, C.; *Heterocycles* **2010**, *80*,133-139. (h) Whelligan, D. K.; Thomson, D. W.; Taylor, D.; Hoelder, S.; *J. Org. Chem*. **2010**, *75*, 11-15.

(6)Yu, M.; Pagenkopf, B. L. *J. Am. Chem. Soc*. **2003**, *125*, 8122–8123.

(7)Yu, M.; Pagenkopf, B. L. *Org. Lett.* **2003***, 5*, 5099–5101.

(8)Yu, M.; Pantos, G. D.; Sessler, J. L.; Pagenkopf, B. L. *Org. Lett*. **2004**, *6*, 1057–1059.

(9) Morra, N. A.; Morales, C. L.; Bajtos, B.; Wang, X.; Jang H.; Wang, J., Yu, M.; Pagenkopf, B. L., *Adv. Synth. Catal*. **2006**, *348*, 2385–2390.

(10) (a) Morales, C. L.; Pagenkopf, B. L. *Org. Lett.* **2008**, *10*, 157–159. (b) Bajtos, B.; Pagenkopf, B. L., *Eur. J. Org. Chem.* **2009**, 1072–1077.

(11) (a) Reissig, H.-U. *Top. Curr. Chem.* **1988**, *144* , 73–135. (b) Reissig, H.-U.; Zimmer, R. *Chem. Rev.* **2003**, *103*, 1151–1196 (c) Yu, M.; Pagenkopf , B. L. *Tetrahedron* **2005**, *61*, 321–347. (d) Carson, C. A.; Kerr, M. A. *Chem. Soc. Rev*. **2009**, *38*, 3051–3060.

(12) Bridges, T. M.; Brady, A. E.; Kennedy, J. P.; Daniels, R. N.; Miller, N. R.; Kim, K.; Breininger, M. L.; Gentry, P. R.; Brogan, J. T.; Jones, C. K.; Conn, P. J.; Lindsley, C. W. *Bioorg. Med. Chem. Lett.* **2008**, *18*, 5439–5442.

(13) Gassman, P. G.; Burns, S. J. *J. Org. Chem*. **1988**, *53*, 5576–5578.

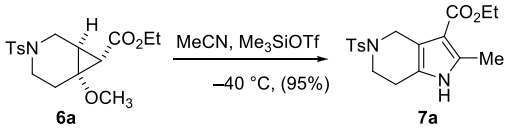
(14) Charles, R. G. *J. Org. Chem*. **1957**, *22*, 677–679.

(15) Engler, T. A.; Wanner, J. *J. Org. Chem*. **2000**, *65*, 2444–2457.

(16) (a) Benzyl protecting group was first selected to allow for an easy deprotection in the subsequent oxidation step (b) Both diastereomers work equally well in the subsequent cyclization.

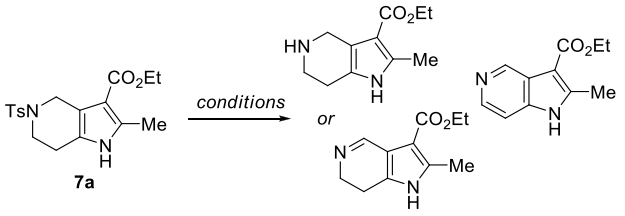
With cyclopropane **6** in hand it was allowed to react with acetonitrile under the standard annulation conditions (1.0 equiv. $Me_3SiOTf$, –40 °C) to give the tetrahydropyrrolopyridine **7a** in 95% isolated yield (Scheme 4).[7] This material was easily and economically prepared on gram scale, and was selected as a model substrate for screening oxidation conditions to provide the desired azaindole nucleus (Table 1). It was thought that either a two step sequence involving elimination or deprotection of the tosylate followed by oxidation would be acceptable, as well as a one step process to give the azaindole directly. Various strategies were explored, including strong bases,[17] Na-naphthalenide,[18] DDQ,[19] Pd/C,[10] and $MnO_2$.[20] In each case, either decomposition or no reaction was observed (Table 2, entries 1– 6). Ultimately it was found that $SeO_2$ executed the desired oxidation extraordinarily well and afforded the azaindole in 92% isolated yield.[21]

**Scheme 4**. Nitrile annulation




**6a** **7a**

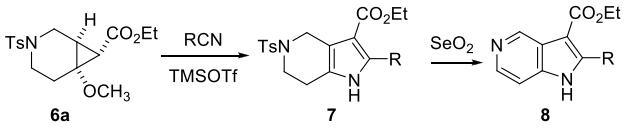
**Table 1**. Deprotection and oxidation



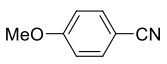
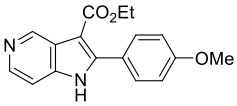
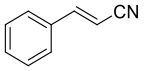
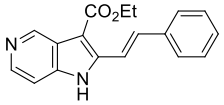
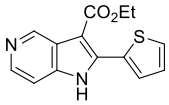

| entry | conditions | yield (%) |
|---|---|---|
| 1 | MeONa/MeOH | decomposition |
| 2 | *t*BuOK/*t*BuOH | decomposition |
| 3 | Na-naphthalenide/THF | decomposition |
| 4 | DDQ/toluene | decomposition |
| 5 | 5% Pd/C, mesitylene | no reaction |
| 6 | $MnO_2$,$CH_2Cl_2$ | no reaction |
| 7 | $SeO_2$, dioxane | 92% (azaindole) |

With reaction conditions established for both the nitrile annulation and subsequent oxidation the reaction scope was explored, and the results are summarized in Table 2. The reaction works well with other aliphatic nitriles (entry b) as well as benzylic and electron rich benzylic nitriles (entries c and d). Unsaturated nitriles are effective (entry e) as are those containing heteroatoms, such as 2-thiophenecarbonitrile (entry f). The annulation reaction is conveniently run with a large excess of nitrile as solvent, but where this is impractical, nitromethane was employed. Sterically hindered (e.g., pivalonitrile and isobutyronitrile) or electron deficient nitriles (e.g., 4-bromobenzonitrile) did not engage in the reaction.

**Table 2**. Scope of Azaindole Synthesis[a]




**6a** **7** **8**

| entry | nitrile | azaindole | ann. yield | ox. yield |
|---|---|---|---|---|
| a | MeCN | R = Me | 95% | 92% |
| b | EtCN | R = Et | 62% | 94% |
| c | PhCN | R = Ph | 92% | 97% |
| d |  |  | 86% | 81% |
| e |  |  | 69% | 61% |
| f |  |  | 87% | 61% |

[a] Cycloaddition reactions were run at –40 °C using 1.0 equiv of cyclopropane, 2.0 equiv nitrile, 1.0 equiv $Me_3SiOTf$ in nitromethane solvent. In the case of acetonitrile (entry a), excess nitrile was used as solvent. Oxidation conditions: 5 equiv of $SeO_2$ in refluxing dioxane.

We have shown previously that other functional groups can react in formal dipolar cycloadditions with DA cyclopropanes, including electron deficient pyridines[9] and indoles.[22] While not intended to be exhaustive, Table 4 shows that the 3,4-cyclopropanopiperidine reacts analogously to afford fused azaindoles very efficiently. The reactions with both 4-cyanopyridine and 2-cyanopyridine gave their respective tetrahydro-pyridoindolizines (Table 3, entries a and b), and both underwent oxidation with $SeO_2$ to the pyridoindolizine. The single crystal x-ray structure of **10b** was solved and

(17) Harrison, D. M.; Sharma, R. B. *Tetrahedron Lett*. **1986**, *27*, 521-–524.

(18) Becker, M. H.; Chua, P.; Downham, R.; Douglas, C. J.; Garg N. K.; Hiebert, S.; Jaroch, S.; Matsuoka, R. T.; Middleton, J. A.; Ng, F. W.; Overman, L. E. *J. Am. Chem. Soc.* **2007**, *129*, 11987–12002.

(19) Wallace, D. J.; Gibb, A. D.; Cottrell, I. F.; Kennedy, D. J.; Brands, K. M. J.; Dolling, U. H. *Synthesis* **2001**, *12*, 1784–1789.

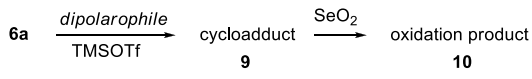
(20) Bagley, M. C.; Lubinu, M. C. *Synthesis* **2006**, *8*, 1283–1288.

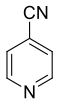
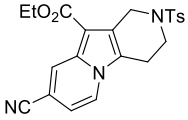
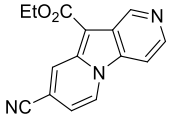
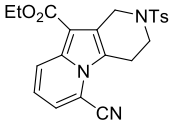
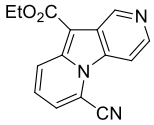
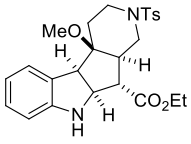
(21) Gatta, F.; Misiti, D. *J. Heterocycl. Chem*. **1987**, *24*, 1183–1187.

(22) Bajtos, B.; Yu, M.; Zhao, H.; Pagenkopf, B. L. *J. Am. Chem. Soc.* **2007**, *129*, 9631–9634.

the ORTEP is presented in Figure 2. The cycloaddition with indole provided the cycloadduct **9c** in 57% yield, but the standard $SeO_2$ oxidation conditions were ineffective in this case.

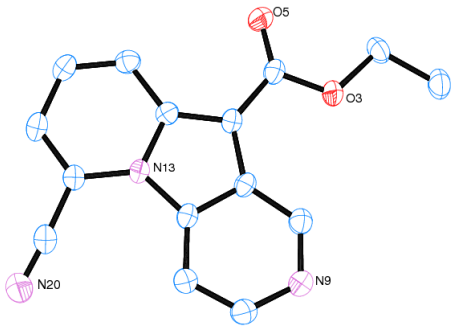
**Table 3**. [3+2] Cycloannulation between pyridines and indole with cyclopropane **6a**




| entry | dipolarophile | cycloadduct (**9**)/yield | oxidation product (**10**)/yield |
|---|---|---|---|
| a |  |  71% |  99% |
| b |  |  53% |  64% |
| c[a] |  |  57% | decomposition |

[a] Relative stereochemistry was not determined but was assigned by analogy only. For a relevant discussion with similar systems, see reference 22.

**Figure 2**. X-ray structure of **10b**




In summary, we have reported a novel and practical two step sequence for the preparation of C2 substituted 5-azaindoles and fused azaindoles, in 34-87% overall yield. The synthetic sequence starts with an easily prepared and inexpensive piperidine based DA cyclopropane, which is then allowed to react with nitriles, pyridines and indoles. A subsequent $SeO_2$ mediated oxidation cleaves the tosyl protecting group and oxidizes the substrates to provide the aromatic azaindoles.

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**Supporting Information Available:** General experimental procedures and characterization of all new compounds, and copies of NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.