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Selective Amination of Polyhalopyridines Catalyzed by a Palladium–Xantphos Complex

Jianguo Ji,* Tao Li, and William H. Bunnelle

Neuroscience Research, Global Pharmaceutical Research and Development, Department-R47W, AP9A-1, Abbott Laboratories, 100 Abbott Park Road, Abbott Park, Illinois 60064

jianguo.ji@abbott.com

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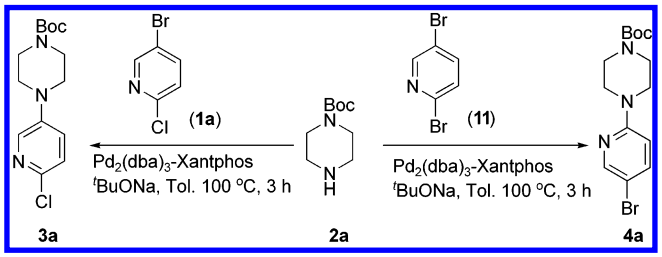
ABSTRACT



Amination of 5-bromo-2-chloropyridine (1a) catalyzed by a palladium–Xantphos complex predominately gives 5-amino-2-chloropyridine product 3a in 96% isolated yield and excellent chemoselectivity (3a/4a = 97:3). Amination of 2,5-dibromopyridine (11) under the same conditions exclusively affords 2-amino-5-bromopyridine 4a.

Synthetic approaches to aminopyridine derivatives continue to receive considerable attention due to their presence in biologically active pharmaceutical ingredients and numerous natural products.[1] Strategies for selective synthesis of aminopyridine derivatives include modification of commercially available aminopyridines,[2] selective nitration and reduction of pyridines,[3] and de novo construction of a pyridine nucleus incorporating properly disposed amino groups,[4] as well as nucleophilic substitution of halopyridines with amines under thermal conditions.[5] These methods generally require harsh reaction conditions or lengthy reaction sequences. The selective and efficient synthesis of aminopyridines under mild conditions is still regarded as a nontrivial synthetic challenge. The development of the palladium-catalyzed amination of aryl halides in the mid-1990s by Buchwald[6] and Hartwig[7] has provided a general and practical method to synthesize a wide variety of arylamines from readily available aryl halides.[8] Recently, Maes and Dommisse[9] reported that selective palladium-catalyzed amination of chloroiodo- and dichloropyridines could be accomplished with aromatic or heteroaromatic amines.[10] In connection with our medicinal

(1) (a) Quintela, J. M.; Peinador, C.; González, L.; Iglesias, R.; Paramá, A.; Alvarez, F.; Sanmartín, M. L.; Riguera, R. *Eur. J. Med. Chem.* **2003**, *38*, 265. (b) O'Hagan, D. *Nat. Prod. Rep.* **2000**, *17*, 435. (c) van Rhee, A. M.; Jiang, J.; Melman, N.; Olah, M. E.; Stiles, G. L.; Jacobson, K. A. *J. Med. Chem.* **1996**, *39*, 2980. (d) Bever, C. T., Jr. *CNS Drug Rev.* **1995**, *1*, 261.

(2) Balboni, G.; Marastoni, M.; Merighi, S.; Borea, P. A.; Tomatis, R. *Eur. J. Med. Chem.* **2000**, *35*, 979.

(3) Chen, B.-C.; Hynes, J. Jr.; Pandit, C. R.; Zhao, R. *Heterocycles* **2001**, *55*, 951.

(4) Gfesser, G. A.; Bayburt, E. K.; Cowart, M.; DiDomenico, S.; Gomtsyan, A.; Lee, C.-H.; Stewart, A. O.; Jarvis, M. F.; Kowaluk, E. A.; Bhagwat, S. S. *Eur. J. Med. Chem.* **2003**, *38*, 245.

(5) Brodbeck, B.; Püllmann, B.; Schmitt, S.; Nettekoven, M. *Tetrahedron Lett.* **2003**, *44*, 1675.

(6) Guram, A. S.; Rennels, R. A.; Buchwald, S. L. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1348.

(7) Louie, J.; Hartiwig, J. F. *Tetrahedron Lett.* **1995**, *36*, 3609.

(8) For recent reviews, see: (a) Muci, A. R.; Buchwald, S. L. *Top. Curr. Chem.* **2002**, *219*, 131. (b) Hartwig, J. F. *Angew. Chem., Int. Ed.* **1998**, *37*, 2046. (c) Baranano, D.; Mann, G.; Hartwig, J. F. *Curr. Org. Chem.* **1997**, *1*, 287. (d) Frost, C. G.; Mendonca, P. *J. Chem. Soc., Perkin Trans. 1* **1998**, 2615.

(9) (a) Maes, B. U. W.; Loones, K. T. J.; Jonckers, T. H. M.; Lemière, G. L. F.; Dommisse, R. A.; Haemers, A. *Synlett* **2002**, 1995. (b) Jonckers, T. H. M.; Maes, B. U. W.; Lemière, G. L. F.; Dommisse, R. *Tetrahedron* **2001**, *57*, 7027.

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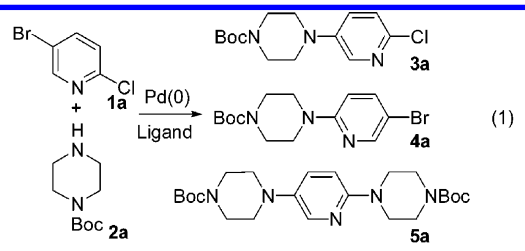
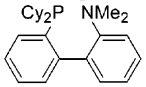
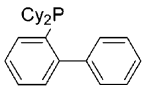
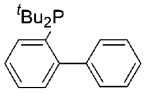
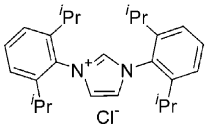
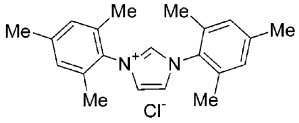
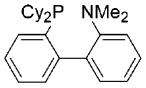
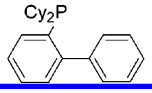
chemistry program at Abbott Laboratories, a series of aminohalopyridines was prepared. We concluded that palladium-catalyzed amination of readily available polyhalopyridines could be used to efficiently synthesize the target molecules. Here we report aminations of 5-bromo-2-chloro- and 2,5-dibromopyridine with cyclic alkylamines[11] under catalysis by a palladium−Xantphos complex with excellent levels of regioselectivity and high chemical yields.

The amination of 5-bromo-2-chloropyridine (**1a**) with 1-*N*-Boc-piperazine (**2a**) in toluene at 100 °C was initially selected as a model reaction for investigating the chemoselectivities and the efficiencies of various Pd-ligand catalyst systems (eq 1).[12] A survey of several ligands that are commonly utilized for *N*-arylation is summarized in Table 1. Equimolar quantities of **1a** and **2a** were combined with 1.5 equiv of ^{t}BuONa in toluene and allowed to react in the presence of $Pd_2(dba)_3$ (2 mol %) and the test ligand (6 mol %) for 3 h at 100 °C. The chemical yields and the ratio of the products were determined by HPLC. DPPF [1,1′-bis-(diphenyl-phosphino)ferrocene] and BINAP [2,2′-bis-(diphenyl-phosphino)-1,1′-binaphthyl], which are commonly employed in *N*-arylation,[8a,12] led to coupling with relatively poor chemoselectivity providing a mixture of **3a** and **4a** in low to moderate chemical yields (Table 1, entries 1 and 2). In the case of BINAP, a small amount of diaminopyridine byproduct **5a** was also observed (Table 1, entry 2). In the presence of Xantphos, a chelating bidentate bisphosphine ligand with a wide bite angle that is widely employed in transition-metal-catalyzed couplings,[13] the reaction proceeds with excellent chemoselectivity favoring **3a**, but at the expense of increased quantities of the bis-aminated product **5a** (Table 1, entry 3). Several sterically encumbered and electron-rich monodentate phosphine ligands, such as Cy-MAP [(2′-dicyclohexylphosphanylbiphen-2-yl)dimethylamine], Cy_2P(Ph-Ph) (dicyclohexyl-2-biphenylphosphane), $^t Bu_2P$(Ph-Ph) (di-*tert*-butyl-2-biphenylphosphane),[14] and $^t Bu_3P$[15] also

Table 1. Effect of Ligands on Palladium-Catalyzed Chemoselective Amination of **2a** with 5-Bromo-2-chloropyridine (**1a**)[a]



entry	ligand	**3a** (%)[b]	**3a** : **4a** : **5a**[c]
1	DPPF	12	72 : 2 : 0
2	BINAP	72	74 : 21 : 5
3	Xantphos	70	87 : 0 : 13
4		59	81 : 0 : 19
5		64	92 : 0 : 8
6		65	96 : 4 : 0
7	$^t Bu_3P$	62[d]	99 : 0 : 1
8		79	87 : 9 : 4
9		18	23 : 76 : 1
10	Xantphos	96[e]	97 : 3 : 0
11	$^t Bu_3P$	97[d,e]	97 : 3 : 0
12		95[e]	96 : 2 : 2
13		72[e]	95 : 3 : 2

[a] General reaction conditions: Under N_2, a mixture of **1a** (1 mmol), **2a** (1 mmol), $Pd_2(dba)_3$ (0.02 mmol), ligand (0.06 mmol), and ^{t}BuONa (1.5 mmol) in toluene (0.1 M) was stirred at 100 °C for 3 h. [b] HPLC assay yield. [c] The ratio was detemined by HPLC. [d] $Pd_2(dba)_3$ (0.01 mmol) and $(^t Bu_3P)_2Pd$ (0.02 mmol) were used. [e] 1.3 mmol of **1a** was used.

provided excellent levels of chemoselectivity with moderate chemical yields (Table 1, entries 4−7). The nucleophilic heterocyclic carbene ligand[16] IPr·HCl (IPr = 1,4-bis(2,6-diisopropyl)imidazol-2-ylidene) resulted in greater than 9:1

(10) Some recent examples of Pd-catalyzed N-arylation with aminopyridines: (a) Yin, J.; Zhao, M. M.; Huffman, M. A.; McNamara, J. M. *Org. Lett.* **2002**, *4*, 3481. (b) Yang, J.-S.; Lin, Y.-H.; Yang, C.-S. *Org. Lett.* **2002**, *4*, 777. (c) Arterburn, J. B.; Pannala, M.; Gonzalez, A. M. *Tetrahedron Lett.* **2001**, *42*, 1475. (d) Khan, M. M.; Ali, H.; van Lier, J. E. *Tetrahedron Lett.* **2001**, *42*, 1615.

(11) Trudell et al. reported a palladium-catalyzed amination of 2-chloro-5-iodopyridine with 7-azabicyclo[2.2.1]heptane. Chen, J.; Trudell, M. L. *Org. Lett.* **2001**, *3*, 1371.

(12) For systematic studies of Pd−ligand combination in the amination of aryl halides, see: (a) Hamann, B. C.; Hartwig, J. F. *J. Am. Chem. Soc.* **1998**, *120*, 3694. (b) Wolfe, J. P.; Buchwald, S. L. *J. Org. Chem.* **2000**, *65*, 1144. (c) Wolfe, J. P.; Tomori, H.; Sadighi, J. P.; Yin, J.; Buchwald, S. L. *J. Org. Chem.* **2000**, *65*, 1158. (d) Harris, M. C.; Geis, O.; Buchwald, S. L. *J. Org. Chem.* **1999**, *64*, 6019.

(13) Xantphos was first developed by van Leeuwen and co-workers: (a) Kraneburg, M.; van der Burgt, Y. E. M.; Kamper, P. C. J.; van Leeuwen, P. W. N. M. *Organometallics*, **1995**, *14*, 3081. For excellent reviews on Xantphos ligands in transition-metal complexes and catalysis, see: (b) van Leeuwen, P. W. N. M.; Kamer, P. C. J.; Reek, J. N. H.; Dierkes, P. *Chem. Rev.* **2000**, *100*, 2741. (c) Kamer, P. C. J.; van Leeuwen, P. W. N. M.; Reek, J. N. H. *Acc. Chem. Res.* **2001**, *34*, 895. For recent examples using palladium-Xantphos in *N*-arylations, see: refs 9, 10a, 12, and: (d) Yin, J.; Buchwald, S. L. *J. Am. Chem. Soc.* **2002**, *124*, 6043. (e) Guari, Y.; van Strijdonck, G. P. F.; Boele, M. D. K.; Reek, J. N. H.; Kamer, P. C. J.; van Leeuwen, P. W. N. M. *Chem. Eur. J.* **2001**, *7*, 475. (f) Sergeev, A. G.; Artamkina, G. A.; Beletskaya, I. P. *Tetrahedron Lett.* **2003**, *44*, 4719. (g) Browning, R. G.; Mahmud, H.; Badarinarayana, V.; Lovely, C. J. *Tetrahedron Lett.* **2001,** *42*, 7155. Examples using palladium−Xantphos in C−S bond formation: Cacchi, S.; Fabrizi, G.; Goggiamani, A.; Parisi, L. M. *Org. Lett.* **2002**, *4*, 4719.

(14) Old, D. W.; Wolfe, J. P.; Buchwald, S. L. *J. Am. Chem. Soc.* **1998**, *120*, 9722 and ref 12(d).

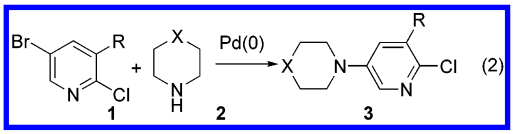
(15) Pd/$^t Bu_3P$ complex was in situ prepared by using $Pd_2(dba)_3$ (1 mol %) and $(^t Bu_3P)_2Pd$ (2 mol %): Littke, A. F.; Fu, G. C. *Angew. Chem., Int. Ed.* **2002**, *41*, 4176. Recent examples using $^t Bu_3P$ in *N*-arylation: (a) Prashad, M.; Mak, X. Y.; Liu, Y.; Repic, O. *J. Org. Chem.* **2003**, *68*, 1163. (b) Lee, M.; Jørgensen, J.; Hartwig, J. F. *Org. Lett.* **2001**, *3*, 2729. (c) Yamamoto, T.; Nishiyama, M.; Koie, Y. *Tetrahedron Lett.* **1998**, *39*, 2367.

(**3a** vs **4a**) chemoselectivity in 79% yield (Table 1, entry 8). In contrast, the reaction with IMes·HCl (IMes = 1,3-bis-(2,4,6-trimethylphenyl)imidazol-2-ylidene) favored formation of **4a**[17] (Table 1, entry 9).

Despite the excellent selectivity using Xantphos and several sterically encumbered monodentate ligands (Table 1, entries 3−7), the reaction proceeded in only 59−70% chemical yields, often contaminated with the 2,5-diaminopyridine byproduct **5a**. In an attempt to improve the reaction efficiency, the effect of base was investigated. Under a standard set of conditions (equimolar quantities of **1a** and **2a** were catalyzed by $Pd_2(dba)_3$−Xantphos in toluene at 100 °C for 3 h), use of ^{t}BuONa provided **3a** in 70% yield along with **5a** (Table 1, entry 3). The stronger base ^{t}BuOK gave somewhat inferior results (**3a**, 56%; **3a**/**4a**/**5a** = 79:16:5). The reaction with Cs_2CO_3 was quite sluggish (12% conversion of **1a** over 3 h). Several other bases (K_3PO_4, K_2CO_3, DABCO, DBU, and Et_3N) were screened, but none of these led to detectable conversion of **1a**. HPLC analysis of the reactions with ^{t}BuOK and ^{t}BuONa (Table 1, entries 1−7) showed complete disappearance of starting material **1a** within 3 h. LC-MS revealed the existence of several possible bipyridines, such as 6,6′-dichloro[3,3′]bipyridine **6**.[18]

The postulated mechanism for the palladium-catalyzed *N*-arylation[19] involves oxidative addition of Pd(0) to the carbon-halo bond in **1a**,[20] exchange of **2a** for halide in the palladium complex,[21] and reductive elimination of the corresponding aza-pyridinyl-palladium complex.[22] In this scenario, the ratio of **3a**/**4a** is determined by the regioselectivity of the oxidative addition step, its reversibility, and the reactivity of the respective palladium complexes. Both **3a** and **4a** can undergo further reaction with excess **2a** to produce **5a**.[23] The presence of **5a** in the final reaction mixture obscures direct observation of the selectivity of **3a**/**4a**. Use of an excess of **1a** should diminish the production of **5a** and reveal the intrinsic chemoselectivity of the reaction. When 1.3 equiv of **1a** was employed under similar conditions, the reaction proceeded in excellent chemical yields and superior selectivity without producing **5a** by using either Xantphos or ^{t}Bu$_3$P ligand (Table 1, entries 10 and 11). Similar improvements were also seen with either CyMAP or Cy$_2$P-(Ph-Ph) ligand (Table 1, entries 12 and 13). Xantphos is a commercially available, air stable and easily handled crystalline solid. As a typical bidentate bisphosphine ligand with wide bite angle, its coordination properties and synthetic uses have been well documented.[14] The $Pd_2(dba)_3$−Xantphos combination was selected as the preferred catalytic system. Consequently, under the catalysis of $Pd_2(dba)_3$ (2 mol %) and Xantphos (6 mol %), amination of 5-bromo-2-chloropyridine (**1a**) (1.3 equiv) with 1-*N*-Boc-piperazine in toluene predominately gave 1-*N*-Boc-4-*N*-(6-chloropyridin-3-yl)piperazine **3a** in 96% yield with excellent chemoselectivity (**3a**/**4a**/**5a** = 97:3:0) at 100 °C over 3 h.

Table 2. Chemoselective Amination of Cyclic Amines **2** with 5-Bromo-2-chloropyridines (**1**) Catalyzed by a Palladium−Xantphos Complex[a]



entry	R	X	3	yield[b] (%)
1	H	NBoc	**3a**	96
2	Me	NBoc	**3b**	90
3	Cl	NBoc	**3c**	87
4	H	O	**3d**	99
5	H	CH_2	**3e**	94
6	H	MeCH	**3f**	95
7	H	PhN	**3g**	93
8	H	MeN	**3h**	87
9	H	BnN	**3i**	97

[a] General reaction conditions: Under N_2, a mixture of **1a** (1.3 mmol), **2a** (1 mmol), $Pd_2(dba)_3$ (0.02 mmol), Xantphos (0.06 mmol), and ^{t}BuONa (1.5 mmol) in toluene (0.1 M) was stirred at 100 °C for 3 h. [b] Isolated yield.

Encouraged by these results, we further explored the scope and limitations of the $Pd_2(dba)_3$−Xantphos catalyst system (eq 2). The results are summarized in Table 2. Under the standard conditions summarized in the Table, amination of **1** with a variety of cyclic amines **2** furnished 5-amino-2-chloropyridines **3** with excellent chemoselectivity and in high isolated yields. In each case, amination occurs at the more reactive C−Br bond, and the chloro substituent remains unchanged.[24] The basicity of amine **2**, as modulated by changes in substituent X, had little effect on either chemoselectivity or chemical yields (Table 2, entries 1 and 4−9).[25]

The regioselectivity for the amination of 2,5-dibromopyridine[26] (**11**) was also evaluated (eq 3). The results are

(16) (a) Arduengo, A. J., III. *Acc. Chem. Res.* **1999**, *32*, 913. Examples using heterocyclic carbene ligands in *N*-arylation: (b) Huang, J.; Grasa, G.; Nolan, S. P. *Org. Lett.* **1999**, *1*, 1307. (c) Stauffer, S. R.; Lee, S.; Stambuli, J. P.; Hauck, S. I.; Hartwig, J. F. *Org. Lett.* **2000**, *2*, 1423.

(17) By using Pd-bisimidazolium (a modified IPr·HCl ligand by Trudell) complex, the reaction of 2-chloro-5-iodopyridine with 7-azabicyclo[2.2.1]-heptane was reported to give predominantly 7-(5-iodo-2-pyridinyl)-7-azabicyclo[2.2.1]heptane. See ref 11.

(18) Repetition of the experiment of entry 3 (Table 1) in absence of amine **2a** produced **6** as the major product in 56% isolated yield.

(19) (a) Wolfe, J. P.; Wagaw, S.; Marcoux, J.-F.; Buchwald, S. L. *Acc. Chem. Res.* **1998**, *31*, 805. (b) Hartwig, J. F. *Acc. Chem. Res.* **1998**, *31*, 852.

(20) (a) Paul, F.; Patt, J.; Hartwig, J. F. *Organometallics* **1995**, *14*, 3030. (b) Hartwig, J. F.; Paul, F. *J. Am. Chem. Soc.* **1995**, *117*, 5373.

(21) (a) Hartwig, J. F. *Synlett* **1997**, 329. (b) Widenhoefer, R. A.; Buchwald, S. L. *Organometallics* **1996**, *15*, 2755.

(22) Driver, M. S.; Hartwig, J. F. *J. Am. Chem. Soc.* **1997**, *119*, 8232.

(23) When **2a** (2.5 mmol) reacted with **1a** (1.0 mmol) under the catalysis of by $Pd_2(dba)_3$−Xantphos with ^{t}BuONa (2.5 mmol) in toluene at 100 °C for 3 h, **5a** was obtained in 96% yield.

(24) Under the standard conditions summarized in the Table 2, amination of **2a** with 4-bromo-2-chloropyridine (**7**) and 3-bromo-2-chloropyridine (**8**) provided the corresponding 1-*N*-Boc-4-(2-chloropyridin-4-yl)-piperazine (**9**) and 1-*N*-Boc-4-(2-chloropyridin-3-yl)-piperazine (**10**) in 91% and 87% isolated yields, respectively (eq 4).

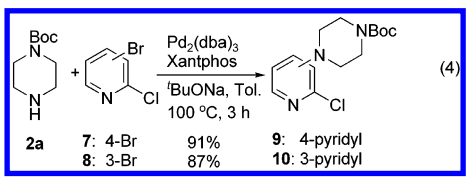
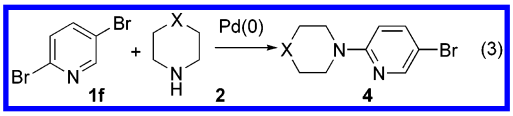


Table 3. Regioselective Amination of 2,5-Dibromopyridine (**1f**) Catalyzed by a Palladium−Xantphos Complex[a]



entry	X	4	yield[b] (%)
1	NBoc	**4a**	99
2	O	**4b**	99
3	CH_2	**4c**	98
4	MeCH	**4d**	98
5	PhN	**4e**	95
6	MeN	**4f**	99
7	BnN	**4g**	96

[a] General reaction conditions: Under N_2, a mixture of **1f** (1.3 mmol), **2a** (1 mmol), $Pd_2(dba)_3$ (0.02 mmol), Xantphos (0.06 mmol), and ^{t}BuONa (1.5 mmol) in toluene (0.1 M) was stirred at 100 °C *for 3* h. [b] Isolated yield.

tabulated in Table 3. Under the standard conditions with 30% excess **11**, **4a** was produced in virtually quantitative yield (Table 3, entry 1) and with no trace of the regioisomeric product or the diaminated material **5a**. However, the reaction of equimolar **11** and **2a** under the catalysis by $Pd_2(dba)_3$−Xantphos afforded **4a** in only 87% yield (**4a**/**5a** = 97:3),[27] while the use of $Pd_2(dba)_3$ (2 mol %)−BINAP (6 mol %) gave a mixture of **4a** and **5a** in 40% yield (**4a**/**5a** = 84:16). In the case of $Pd_2(dba)_3$−BINAP catalytic system, use of excess **11** (1.3 mmol) gave **4a** in 72% yield with slightly improved selectivity (**4a**/**5a** = 89:11). A number of cyclic amines **2** were examined under the standard conditions of $Pd_2(dba)_3$−Xantphos catalytic system, and all provided the single aminated product **4** in excellent yield (Table 3, entries 2−7). The basicity of amine **2** was noticed again to have little effect on either selectivity or chemical yield.

In summary, we have achieved a chemoselective amination of 5-bromo-2-chloropyridine under catalysis by $Pd_2(dba)_3$−Xantphos with ^{t}BuONa in toluene at 100 °C for 3 h. The reaction predominately gives 5-amino-2-chloro-pyridine products **3** in good chemical yield and excellent chemoselectivity (**3**/**4**/**5** ≥ 97:3:0). Amination of 2,5-dibromopyridine selectively provides 2-amino-5-bromopyridines **4** in quantitative yields. Further investigations including further reaction optimization and synthetic applications will be reported shortly.

Acknowledgment. We thank Drs. Michael J. Dart and Michael R. Schrimpf for their helpful discussions.

Supporting Information Available: Experimental procedures and spectral data for the products **3**−**5**, **9**, and **10**. This material is available free of charge via the Internet at http://pubs.acs.org.

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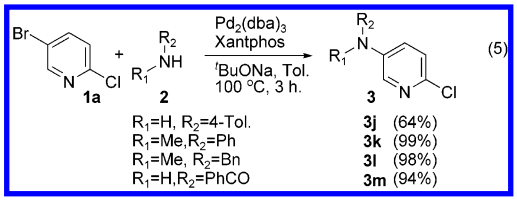
(25) Noncyclic amines also react efficiently with **1a** under these conditions (equation 5). For example, reaction of 4-methylaniline with **1a** provided **3j** in 64% isolated yield, along with 27% of the bis(arylated) byproduct *N*,*N*-bis-(6-chloropyridin-3-yl)-4-methylaniline. In this case, use of Cs_2CO_3 as base led to a much slower reaction (18 h) but greatly improved yield of **3j** (91%) owing to diminished conversion to the bis(arylated) byproduct (7%). Bis(arylation) is not an issue with the secondary amines *N*-methylaniline and *N*-methylbenzylamine, which furnished **3k** and **3l** in excellent yields under the standard conditions. Benzamide reacts smoothly to provide the monoarylated product **3m**.



(26) **2a** (2.5 mmol) reacted with **1f** (1.0 mmol) under the catalysis by $Pd_2(dba)_3$-Xantphos with ^{t}BuONa (2.5 mmol) in toluene at 100 °C for 3 h affording **5a** in 54% isolated yield.

(27) Amination of 2,5-dibromopyridine using palladium catalysts: (a) Gomtsyan, A.; Didomenico, S.; Lee, C.; Matulenko, M. A.; Kim, K.; Kowaluk, E. A.; Wismer, C. T.; Mikusa, J.; Yu, H.; Kohlhaas, K.; Jarvis, M. F.; Bhagwat, S. S. *J. Med. Chem.* **2002**, *45*, 3639. (b) Madar, D.; Kopecka, H.; Pireh, D.; Pease, J.; Pliushchev, M.; Sciotti, R. J.; Wiedeman, P. E.; Djuric, S. W. *Tetrahedron Lett.* **2001**, *42*, 3681. Amination of 2,5-dibromopyridine using copper catalysts: (c) Lang, F.; Zewge, D.; Houpis, I. N.; Volante, R. P. *Tetrahedron Lett.* **2001**, *42*, 3251.