

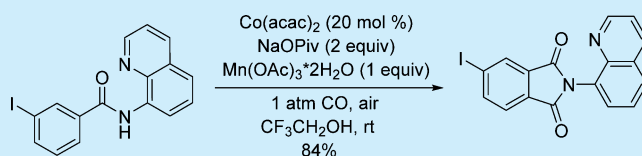
# Cobalt-Catalyzed Direct Carbonylation of Aminoquinoline Benzamides

Liene Grigorjeva and Olafs Daugulis\*

Department of Chemistry, University of Houston, Houston, Texas 77204-5003, United States

**S** Supporting Information

**ABSTRACT:** A method for direct carbonylation of aminoquinoline benzamides has been developed. Reactions proceed at room temperature in trifluoroethanol solvent, use oxygen from air as an oxidant, and require  $\text{Mn}(\text{OAc})_3$  as a cocatalyst. Benzoic and acrylic acid derivatives can be carbonylated by carbon monoxide affording imides in good yields. Halogen, nitro, ether, cyano, and ester functional groups are tolerated. The directing group can be removed under mild conditions affording phthalimides.



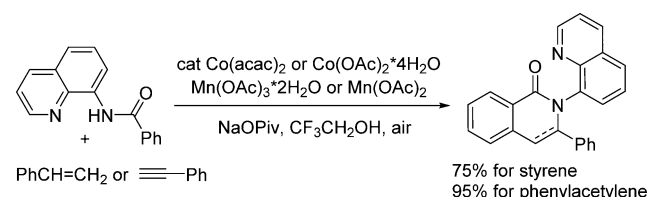
The directing group can be removed under mild conditions

Transition-metal catalyzed carbonylation of aryl halides and sulfonates, pioneered by Heck, has been developed into a versatile synthetic method.<sup>1</sup> However, this methodology requires prefunctionalization of arenes thus introducing additional steps into synthetic sequences. In contrast, direct functionalization of C–H bonds results in more efficient production of the desired substances.<sup>2</sup> Dicobalt octacarbonyl catalyzed carbonylation of azobenzene and Schiff bases reported in 1955 by Murahashi is likely the first example of directed, transition-metal catalyzed functionalization of a C–H bond.<sup>3</sup> The reactions proceed at about 200 °C and under 100–200 atm of CO. More recently, palladium, ruthenium, and rhodium catalysts have been shown to effect carbonylation of  $\text{sp}^2$  and  $\text{sp}^3$  C–H bonds. Specifically, Fujiwara reported palladium-promoted carbonylation of simple arenes under 15 atm of CO pressure.<sup>4a</sup> Ishii has reported palladium-catalyzed carboxylation of electron-rich arenes by employing oxygen as the terminal oxidant.<sup>4b</sup> Yu has shown that free benzoic acids can be *ortho*-carboxylated under 1 atm of CO at 130 °C under Pd catalysis.<sup>4c</sup> Anilide functionality can also direct carboxylation.<sup>4d</sup> If a perfluoroarylamide directing group is employed, even  $\text{sp}^3$  C–H bonds can be carbonylated.<sup>4e</sup> Several other groups have reported palladium-catalyzed  $\text{sp}^2$  C–H bond carbonylation.<sup>4f–k</sup> Nitrogen-directed, rhodium-catalyzed arene carbonylation is also known.<sup>5</sup> Ruthenium-catalyzed directed carbonylation and acylation of C–H bonds has been reported.<sup>6</sup> Most relevant to this work,  $\text{Ru}_3(\text{CO})_{12}$ -catalyzed, bidentate auxiliary-directed carbonylation of  $\text{sp}^2$  and  $\text{sp}^3$  C–H bonds has been disclosed by Chatani.<sup>6b,c</sup> However, mild, first-row transition-metal catalyzed carbonylation of C–H bonds is still unknown.

We have reported that 8-aminoquinoline, picolinamide, and 2-pyridinylmethylamine auxiliaries can be used for palladium and copper-catalyzed C–H bond functionalization.<sup>7</sup> Other research groups have extensively used these auxiliaries for palladium-, ruthenium-, iron-, and copper-catalyzed reactions.<sup>8</sup> We have recently shown that the aminoquinoline auxiliary can direct cobalt-catalyzed C–H activation/alkene and alkyne

migratory insertion sequences, leading to *ortho*-functionalized benzoic acid derivatives (Scheme 1).<sup>9</sup> This led us to investigate

## Scheme 1. Aminoquinoline Amide Coupling with Alkenes and Alkynes



directed *ortho*-carbonylation of aminoquinoline benzamides, since migratory insertion of carbon monoxide into Co(III)–C bonds is known.<sup>10</sup> We report here cobalt-catalyzed, aminoquinoline-directed carbonylation of  $\text{sp}^2$  C–H bonds that proceeds at room temperature under 1 atm of CO, uses oxygen from air as a terminal oxidant, and affords phthalic acid derivatives.

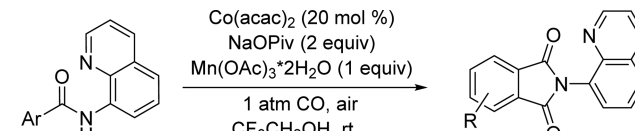
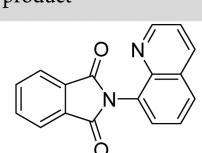
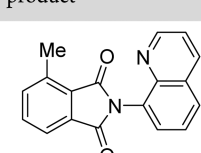
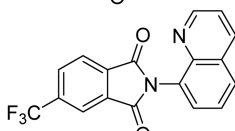
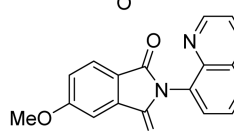
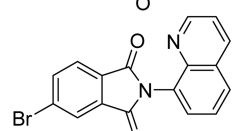
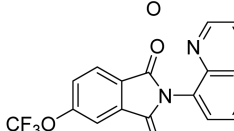
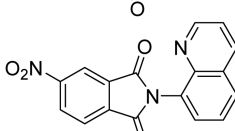
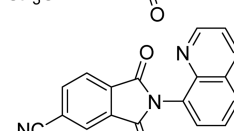
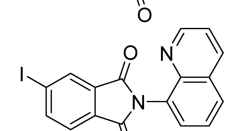
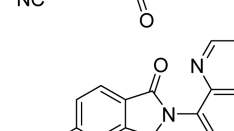
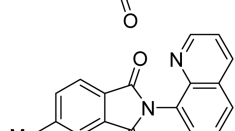
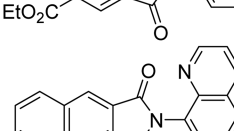
Gratifyingly, conditions that were successful for alkene coupling with  $\text{sp}^2$  C–H bonds<sup>9b</sup> worked also for aminoquinoline benzamide carbonylation. Reactions proceed in trifluoroethanol at room temperature with 20 mol %  $\text{Co}(\text{acac})_3$  catalyst, 1 equiv of  $\text{Mn}(\text{OAc})_3 \cdot 2\text{H}_2\text{O}$  additive, and under 1 atm of CO (Table 1). Oxygen from air is the terminal oxidant, and sodium pivalate base is employed. In all cases, only one isomer of product was obtained.

The reaction scope is presented in Table 1. Aminoquinoline amides possessing electron-withdrawing (entries 2–5, 9–11) as well as electron-releasing substituents (entries 6–8, 12) are reactive. High functional group tolerance is observed. Bromo (entry 3), nitro (entry 4), iodo (entry 5), cyano (entry 10), and ester (entry 11) substituents are tolerated. Carbonylation of

Received: July 9, 2014

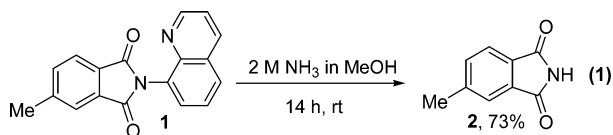
Published: August 22, 2014

Table 1. Carbonylation of Aminoquinoline Amides<sup>a</sup>

							
entry	Ar	product	yield, %	entry	Ar	product	yield, %
1	C <sub>6</sub> H <sub>5</sub>		81	7	2-MeC <sub>6</sub> H <sub>4</sub>		72
2	4-CF <sub>3</sub> C <sub>6</sub> H <sub>4</sub>		83	8	4-MeOC <sub>6</sub> H <sub>4</sub>		94
3	4-BrC <sub>6</sub> H <sub>4</sub>		80	9	4-CF <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>		66
4	3-NO <sub>2</sub> C <sub>6</sub> H <sub>4</sub>		69	10	4-NCC <sub>6</sub> H <sub>4</sub>		75
5	3-IC <sub>6</sub> H <sub>4</sub>		84	11	4-EtO <sub>2</sub> CC <sub>6</sub> H <sub>4</sub>		60
6	4-MeC <sub>6</sub> H <sub>4</sub>		84 91 <sup>b</sup>	12	2-Naphthyl		77

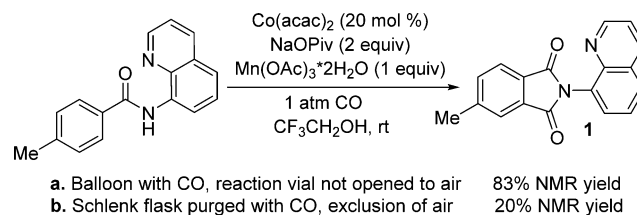
<sup>a</sup>Amide (0.5 mmol), catalyst (0.1 mmol), NaOPiv (1 mmol), Mn(OAc)<sub>3</sub>·2H<sub>2</sub>O (0.5 mmol), trifluoroethanol (5 mL), 1 atm of CO (balloon), 16–60 h. Yields are isolated yields. Please see Supporting Information for details. <sup>b</sup>Scale: 5 mmol.

aminoquinoline *p*-toluoylamide (entry 6) was carried out also on 5 mmol scale, and product was obtained in 91% yield showing that scale-up of the reaction is feasible. The directing group can be easily removed by treatment with ammonia, affording a high yield of a phthalimide derivative (eq 1).



Two control experiments were performed to determine the source of the oxidant. First, *p*-toluoylamide of aminoquinoline was carbonylated under the conditions for Table 1, entry 6, but without opening of the reaction vial to air (Scheme 2). Carbon monoxide was delivered from a balloon equipped with a needle. The NMR yield of product **1** was 83%, which is comparable to the isolated yield for entry 6, Table 1. Second, the reaction was carried out in a CO-filled Schlenk flask (25 mL) with exclusion of oxygen. The NMR yield of the product was 20%. It can be concluded that oxygen is delivered to the reaction via slow diffusion of air through the surface of the balloon.<sup>4f</sup>

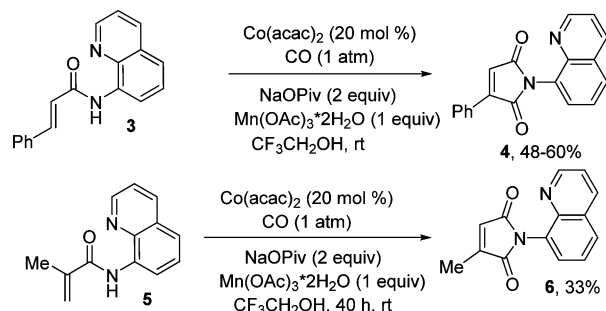
## Scheme 2. Control Experiments



Furthermore, aminoquinoline amides of cinnamic and methacrylic acids can be carbonylated. The products were obtained in moderate yields (Scheme 3).

In conclusion, we have developed a method for directed, room-temperature, cobalt-catalyzed carbonylation of aminoquinoline amide *sp*<sup>2</sup> C–H bonds. Reactions proceed in trifluoroethanol solvent in the presence of the Mn(OAc)<sub>3</sub> cocatalyst and use oxygen from air as an oxidant. Halogen, nitro, ether, cyano, and ester moieties are compatible with the reaction conditions. Directing group removal affords phthalimides.

## Scheme 3. Vinylamide Reactions



## ■ ASSOCIATED CONTENT

## S Supporting Information

Detailed experimental procedures and characterization data for new compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

## ■ AUTHOR INFORMATION

## Corresponding Author

\*E-mail: [olafs@uh.edu](mailto:olafs@uh.edu).

## Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

We thank the Welch Foundation (Grant No. E-1571), NIGMS (Grant No. R01GM077635), and Camille and Henry Dreyfus Foundation for supporting this research.

## ■ REFERENCES

- (1) Schoenberg, A.; Bartoletti, I.; Heck, R. F. *J. Org. Chem.* **1974**, *39*, 3318.
- (2) Reviews: (a) Allen, S. E.; Walvoord, R. R.; Padilla-Salinas, R.; Kozlowski, M. C. *Chem. Rev.* **2013**, *113*, 6234. (b) Hickman, A. J.; Sanford, M. S. *Nature* **2012**, *484*, 177. (c) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624. (d) Ackermann, L. *Chem. Rev.* **2011**, *111*, 1315. (e) Chen, X.; Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2009**, *48*, 5094. (f) Gao, K.; Yoshikai, N. *Acc. Chem. Res.* **2014**, *47*, 1208.
- (3) (a) Murahashi, S. *J. Am. Chem. Soc.* **1955**, *77*, 6403. (b) Murahashi, S.; Horiie, S. *J. Am. Chem. Soc.* **1956**, *78*, 4816.
- (4) (a) Fujiwara, Y.; Kawauchi, T.; Taniguchi, H. *J. Chem. Soc., Chem. Commun.* **1980**, 220. (b) Ohashi, S.; Sakaguchi, S.; Ishii, Y. *Chem. Commun.* **2005**, 486. (c) Giri, R.; Yu, J.-Q. *J. Am. Chem. Soc.* **2008**, *130*, 14082. (d) Giri, R.; Lam, J. K.; Yu, J.-Q. *J. Am. Chem. Soc.* **2010**, *132*, 686. (e) Yoo, E. J.; Wasa, M.; Yu, J.-Q. *J. Am. Chem. Soc.* **2010**, *132*, 17378. (f) Orito, K.; Horibata, A.; Nakamura, T.; Ushito, H.; Nagasaki, H.; Yuguchi, M.; Yamashita, S.; Tokuda, M. *J. Am. Chem. Soc.* **2004**, *126*, 14342. (g) Houlden, C. E.; Hutchby, M.; Bailey, C. D.; Ford, J. G.; Tyler, S. N. G.; Gagné, M. R.; Lloyd-Jones, G. C.; Booker-Milburn, K. I. *Angew. Chem., Int. Ed.* **2009**, *48*, 1830. (h) Guan, Z.-H.; Chen, M.; Ren, Z.-H. *J. Am. Chem. Soc.* **2012**, *134*, 17490. (i) Lang, R.; Shi, L.; Li, D.; Xia, C.; Li, F. *Org. Lett.* **2012**, *14*, 4130. (j) Zhang, H.; Liu, D.; Chen, C.; Liu, C.; Lei, A. *Chem.—Eur. J.* **2011**, *17*, 9581. (k) López, B.; Rodríguez, A.; Santos, D.; Albert, J.; Ariza, X.; Garcia, J.; Granell, J. *Chem. Commun.* **2011**, 47, 1054.
- (5) (a) Guan, Z.-H.; Ren, Z.-H.; Spinella, S. M.; Yu, S.; Liang, Y.-M.; Zhang, X. *J. Am. Chem. Soc.* **2009**, *131*, 729. (b) Du, Y.; Hyster, T. K.; Rovis, T. *Chem. Commun.* **2011**, 47, 12074.
- (6) (a) Ie, Y.; Chatani, N.; Ogo, T.; Marshall, D. R.; Fukuyama, T.; Kakiuchi, F.; Murai, S. *J. Org. Chem.* **2000**, *65*, 1475. (b) Inoue, S.; Shiota, H.; Fukumoto, Y.; Chatani, N. *J. Am. Chem. Soc.* **2009**, *131*, 6898. (c) Hasegawa, N.; Charra, V.; Inoue, S.; Fukumoto, Y.; Chatani,

N. *J. Am. Chem. Soc.* **2011**, *133*, 8070. (d) Moore, E. J.; Pretzer, W. R.; O'Connell, T. J.; Harris, J.; LaBounty, L.; Chou, L.; Grimmer, S. S. *J. Am. Chem. Soc.* **1992**, *114*, 5888.

(7) (a) Zaitsev, V. G.; Shabashov, D.; Daugulis, O. *J. Am. Chem. Soc.* **2005**, *127*, 13154. (b) Shabashov, D.; Daugulis, O. *J. Am. Chem. Soc.* **2010**, *132*, 3965. (c) Tran, L. D.; Popov, I.; Daugulis, O. *J. Am. Chem. Soc.* **2012**, *134*, 18237. (d) Tran, L. D.; Roane, J.; Daugulis, O. *Angew. Chem., Int. Ed.* **2013**, *52*, 6043. (e) Truong, T.; Klimovica, K.; Daugulis, O. *J. Am. Chem. Soc.* **2013**, *135*, 9342. (f) Roane, J.; Daugulis, O. *Org. Lett.* **2013**, *15*, 5842.

(8) Selected examples: Ni: (a) Aihara, Y.; Chatani, N. *J. Am. Chem. Soc.* **2014**, *136*, 898. (b) Song, W.; Lackner, S.; Ackermann, L. *Angew. Chem., Int. Ed.* **2014**, *53*, 2477. Fe: (c) Asako, S.; Ilies, L.; Nakamura, E. *J. Am. Chem. Soc.* **2013**, *135*, 17755. Ru: (d) Rouquet, G.; Chatani, N. *Chem. Sci.* **2013**, *4*, 2201. Pd: (e) Zhang, S.-Y.; He, G.; Nack, W. A.; Zhao, Y.; Li, Q.; Chen, G. *J. Am. Chem. Soc.* **2013**, *135*, 2124. (f) He, G.; Chen, G. *Angew. Chem., Int. Ed.* **2011**, *50*, 5192. Cu: (g) Nishino, M.; Hirano, K.; Satoh, T.; Miura, M. *Angew. Chem., Int. Ed.* **2013**, *52*, 4457.

(9) (a) Grigorjeva, L.; Daugulis, O. *Angew. Chem., Int. Ed.*, in press, DOI: 10.1002/anie.201404579. (b) Grigorjeva, L.; Daugulis, O. *Org. Lett.* **2014**, *16*, DOI: 10.1021/ol502005g.

(10) Lenges, C. P.; White, P. S.; Brookhart, M. *J. Am. Chem. Soc.* **1998**, *120*, 6965.