Rhodium(III)-catalyzed directed peri-C-H alkenylation of anthracene derivatives

Karthikeyan, Jaganathan; Yoshikai, Naohiko

2014

Karthikeyan, J., & Yoshikai, N. (2014). Rhodium(III)-catalyzed directed peri-C-H alkenylation of anthracene derivatives. *Organic letters*, 16(16), 4224-4227.

<https://hdl.handle.net/10356/103704>

<https://doi.org/10.1021/ol501926b>

© 2014 American Chemical Society. This is the author created version of a work that has been peer reviewed and accepted for publication by *Organic Letters*, American Chemical Society. It incorporates referee's comments but changes resulting from the publishing process, such as copyediting, structural formatting, may not be reflected in this document. The published version is available at: [<http://dx.doi.org/10.1021/ol501926b>].

Downloaded on 26 Apr 2023 18:53:22 SGT

Rhodium(III)-Catalyzed Directed *peri*-C–H Alkenylation of Anthracene Derivatives

Jaganathan Karthikeyan and Naohiko Yoshikai*

Division of Chemistry and Biological Chemistry, School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371, Singapore

Supporting Information Placeholder

ABSTRACT: Rhodium(III)-catalyzed oxidative coupling reactions of anthracene-9-carboxylic acid derivatives with electron-deficient olefins are reported. A cationic rhodium(III) catalyst, in combination with a copper(II) oxidant, promotes selective monoalkenylation of anthracene-9-carboxamide, affording 1-alkenylanthracene-9-carboxamide in moderate to good yields. A similar catalytic system also promotes the reaction of anthracene-9-carboxylic acid and an electron-deficient olefin, which affords a lactone derivative through C–H alkenylation followed by intramolecular conjugate addition.

The last few decades have witnessed significant development in the transition metal-catalyzed, directing group-assisted functionalization of aromatic compounds.¹ With the extensive development of transition metal catalysts, heteroatom directing groups, and carbon- and heteroatom-based coupling partners, this strategy now offers a myriad of methods for the conversion of aromatic C–H bonds into C–C and C–heteroatom bonds, some of which have found applications in pharmaceuticals and other functional molecules.² Given this background as well as the importance of polycyclic aromatic hydrocarbons (PAHs) in organic functional materials,³ it sounds somewhat strange that such polyaromatic compounds have not been frequently employed as platforms for practicing the power of directed C–H functionalization.⁴

In the past several years, there has been an explosive development in the rhodium(III)-catalyzed directed C–H functionalization reactions of aromatic compounds under oxidative and nonoxidative conditions.⁵ With respect to oxidative *ortho*-alkenylation with olefins, rhodium(III) catalysis has allowed the use of benzoic acids,⁶ acetanilides,⁷ acetophenones,⁸ benzamides,⁹ benzoic esters,¹⁰ aryl oxime ethers,¹¹ phenol carbamate,¹² and many others¹³ as substrates, which form five- or six-membered rhodacycles as the key intermediates (Scheme 1, eq 1). On the other hand, polyaromatic substrates for directed *peri*-functionalization have been mostly limited to 1-naphthol and 1-aminonaphthalene derivatives that can form a five-membered rhodacycle upon *peri*-C–H activation,¹⁴ and other 1-functionalized naphthalene derivatives typically undergo C–H activation at the *ortho*-position rather than the *peri*-position. To our knowledge, functionalized anthracenes and higher acenes, including readily available anthracene-9-carboxylic acid and its derivatives, have been rarely used as substrates for the rhodium(III) catalysis.¹⁵ With our recent development of a synthetic

route to anthracene derivatives that features cobalt-catalyzed branched-selective addition of aromatic imines to styrenes,^{16,17} we became interested in the possibility of directed and nondirected C–H functionalization of such PAH derivatives. Here, we report on a rhodium(III)-catalyzed oxidative coupling reaction of an anthracene-9-carboxamide and an electron-deficient olefin, which results in selective mono-alkenylation of the proximal *peri*-position of the anthracene core (Scheme 1, eq 2).

Scheme 1. Rhodium(III)-Catalyzed Directed Oxidative C–H Alkenylation with Olefins

Our effort was initially focused on the alkenylation of anthracene-9-yl(pyrrolidin-1-yl)methanone **1a** with ethyl acrylate **2a** (Table

1). Upon screening of various reaction conditions, we managed to promote the desired reaction using $[\text{Cp}^*\text{Rh}(\text{MeCN})_3](\text{SbF}_6)_2$ (5 mol %), $\text{Cu}(\text{OAc})_2 \cdot \text{H}_2\text{O}$ (2 equiv), and 1,2-dichloroethane (DCE) as the catalyst, oxidant, and solvent, respectively, which afforded the *peri*-monoalkenylated product **3aa** in 72% yield (Table 1, entry 1). The use of a combination of Cp^*RhCl_2 dimer and AgSbF_6 instead of the cationic rhodium catalyst resulted in a lower yield (Table 1, entry 2). While a comparable result was obtained using PhCl instead of DCE (Table 1, entry 3), more polar and coordinating solvents such as *t*-AmylOH, 1,4-dioxane, and DMF were detrimental to the reaction (Table 1, entries 4–6). Replacement of the $\text{Cu}(\text{II})$ oxidant to $\text{Ag}(\text{I})$ oxidant such as AgOAc and Ag_2CO_3 led to lower yields (Table 1, entries 7 and 8).

Under the conditions in entry 1, the unreacted starting material **1a** was mostly recovered and no identifiable byproduct was detected. Further modifications of the reaction parameters (e.g., catalyst loading, amount of **2a**, temperature) have not allowed us to achieve significant improvement of the conversion of **1a** and the yield of **3aa**. It should be noted that, when using 10 equiv of **2a**, we observed the formation of a small amount of a *peri*-dialkenylation product (< 5% yield according to ^1H NMR analysis).

Table 1. Screening of Reaction Conditions^a

entry	deviation from standard conditions	yield (%) ^b
1	None	72 ^c
2	$[\text{Cp}^*\text{RhCl}_2]_2/\text{AgSbF}_6$ as the catalyst ^d	49
3	PhCl instead of DCE	65
4	<i>t</i> -AmylOH instead of DCE	36
5	1,4-Dioxane instead of DCE	24
6	DMF instead of DCE	5
7	AgOAc instead of $\text{Cu}(\text{OAc})_2 \cdot \text{H}_2\text{O}$	49
8	Ag_2CO_3 instead of $\text{Cu}(\text{OAc})_2 \cdot \text{H}_2\text{O}$	35

^aThe reaction was performed on a 0.2 mmol scale. ^bDetermined by ^1H NMR using mesitylene as an internal standard. ^cIsolated yield. ^d $[\text{Cp}^*\text{RhCl}_2]_2$ (2.5 mol %) and AgSbF_6 (10 mol %) were used.

With the optimized reaction conditions in hand, we next explored the scope of anthracene amides and olefins for the present *peri*-alkenylation reaction (Table 2). The reactions of **1a** with acrylates proceeded smoothly regardless of the alkyl group, affording the corresponding alkenylation products **3aa–3ae** in yields of 61–80% (Table 2, entries 1–5), while phenyl vinyl sulfone reacted more sluggishly (Table 2, entry 6). Acrylonitrile and styrene failed to participate in the reaction (Table 2, entries 7 and 8). In the coupling with methyl acrylate **2b**, pyrrolidine-derived **1a** afforded the highest yield among tertiary amides examined (Table 2, entry 1), followed by those derived from other cyclic amines (Table 2, entries 9 and 10) and then by *N,N*-dimethyl- and *N,N*-diethylamides

(Table 2, entries 11 and 12). *N*-isopropylamide also underwent the *peri*-alkenylation reaction with **2b** to afford the desired product **3fb** in a moderate yield of 48% (Table 2, entry 13). Note that, in this case, intramolecular cyclization of the amide group and the acrylate moiety was not observed. Anthracene-9-carboxamides bearing extra substituents such as aryl, alkynyl, amino, and bromo groups on the 10-position all participated in the reaction with **2b**, affording the corresponding alkenylation products **3gb–3kb** in reasonable yields (Table 2, entries 14–18).

Table 2. Scope of *peri*-C–H Alkenylation^a

entry	R ¹	R ²	R ³	3, yield (%) ^b
1 ^c	pyrrolidinyl	H	CO_2Et	3aa , 72
2	pyrrolidinyl	H	CO_2Me	3ab , 80
3	pyrrolidinyl	H	CO_2Bu	3ac , 74
4	pyrrolidinyl	H	$\text{CO}_2\text{t-Bu}$	3ad , 64
5	pyrrolidinyl	H	CO_2Bn	3ae , 61
6	pyrrolidinyl	H	SO_2Ph	3af , 36
7	pyrrolidinyl	H	CN	0
8	pyrrolidinyl	H	Ph	0
9	piperidinyl	H	CO_2Me	3bb , 66
10	morpholinyl	H	CO_2Me	3cb , 61
11	NMe ₂	H	CO_2Me	3db , 48
12	NEt ₂	H	CO_2Me	3eb , 42
13	NH ₂ Pr	H	CO_2Me	3fb , 48
14	pyrrolidinyl	Ph	CO_2Me	3gb , 70
15	pyrrolidinyl	<i>m</i> -Tol	CO_2Me	3hb , 71
16	pyrrolidinyl	$\text{PhC}\equiv\text{C}$	CO_2Me	3ib , 64
17	pyrrolidinyl	morpholinyl	CO_2Me	3jb , 64
18	pyrrolidinyl	Br	CO_2Me	3kb , 56

^aThe reaction was performed on a 0.2 mmol scale. ^bIsolated yield. ^c2.5 equiv of ethyl acrylate was used.

As briefly mentioned in the Introduction, the combination of cobalt-catalyzed branched-selective addition of aryl aldimine to styrene and subsequent indium-catalyzed dehydrative cyclization allows for the facile synthesis of methylated anthracene derivatives, such as 7-methyltetraphene **6** (Scheme 2).^{16a} The methyl group of **6** was then converted to a tertiary amide group in a few steps, thus affording unsymmetrical tetraphene-7-carboxamide **11**. Because both of the *peri*-positions of **11** are sterically unhindered, not unexpectedly, the rhodium(III)-catalyzed reaction of **11** and **2b** afforded a mixture of regioisomers **31b** and **31b'** in an approximate ratio of 1:1.

Scheme 2. Alkenylation of Tetraphene-7-carboxamide^a

^aSee the Supporting Information for the conversion of **6** to **11**.

Oxidative *peri*-functionalization of parent anthracene-9-carboxylic acid **7** was also achieved (Scheme 3). Thus, the reactions of **7** and electron-deficient olefins proceeded under modified reaction conditions employing CsOAc as an additive and *t*-amyl alcohol instead of DCE as a solvent, thus affording lactone derivatives **8b**, **8g**, and **8i** in good yields, presumably through C–H alkenylation followed by intramolecular conjugate addition.⁶ Note that the reaction of **7** and **2b** in the absence of CsOAc afforded **8b** in a lower yield of 70%. We speculate that CsOAc acts as a base to facilitate the formation of rhodium(III) anthracene-9-carboxylate, which would be an intermediate prior to C–H activation.¹⁸

Scheme 3. *peri*-C–H Alkenylation/Cyclization of Anthracene-9-carboxylic Acid^a

^aThe reaction was performed on a 0.2 mmol scale.

While our attempts to characterize a reaction intermediate have not been successful, we assume that the present *peri*-alkenylation reaction involves a catalytic cycle that is essentially the same as those proposed for related *ortho*-alkenylation reactions (Scheme 4).⁵ Thus, the rhodium(III) catalyst undergoes *peri*-C–H activation of the anthracene substrate **1** to form a rhodacycle **A** with concomitant deprotonation. Insertion of olefin **2** into the C–Rh bond of **A** gives an alkylrhodium intermediate **B**, which may or may not retain the chelation of the amide oxygen atom. Subsequent β-hydride elimination results in the formation of the product **3** and reduction of rhodium(III) to rhodium(I). Reoxidation of the rhodium(I) species with the copper(II) oxidant regenerates the active rhodium(III) catalyst.

Scheme 4. Plausible Catalytic Cycle

Table 3 summarizes UV-visible absorption and fluorescence properties of **1a** and selected *peri*-alkenylated anthracene derivatives. The starting material **1a** showed multiple absorption and emission peaks reflecting the vibrational fine structure, which is characteristic to anthracene and its simple derivatives (Table 3, entry 1). Such fine structures disappeared in most of the *peri*-alkenylated derivatives (Table 3, entries 2–6), except that the 10-alkynyl derivative **3ib** showed two absorption maxima (Table 3, entry 5). Expectedly, the *peri*-alkenyl group of **3ab** and **3af** caused substantial red shift of λ_{max} and λ_{em} compared to **1a** (Table 3, entries 2 and 3), while further influence of the 10-substituent (**3gb**, **3ib**, **3jb**) was relatively small (Table 3, entries 4–6). The *peri*-alkenylated derivatives showed light blue-green fluorescence (Table 3, entries 2–5), except that the 10-morpholino derivative **3jb** was almost non-fluorescent presumably due to excited state intramolecular electron transfer (Table 3, entry 6).

Table 3. Photophysical Properties of Selected Alkenylated Anthracenes^a

entry	1 or 3	λ _{max} /nm	log ε	λ _{em} /nm ^b	Φ _F ^c
1	1a	347, 366, 385	4.18, 4.36, 4.33	389, 412, 436	0.18
2	3ab	391	4.24	473	0.42
3	3af	394	4.08	485	0.44
4	3gb	401	4.15	484	0.44
5	3ib	417, 438	4.52, 4.51	487	0.55
6	3jb	409	4.13	467	0.028

^aIn CH₂Cl₂. ^bExcited at the longest absorption maxima wavelength except for **1a** (366 nm) and **3ib** (417 nm). ^cDetermined with anthracene as a standard.

In summary, we have demonstrated that a rhodium(III) catalyst is capable of catalyzing *peri*-C–H alkenylation of anthracene-9-carboxamides and anthracene-9-carboxylic acid with electron-deficient alkenes under oxidative conditions. Further improvement of the catalytic activity and exploration of other carbon- and heteroatom-based coupling partners may lead to versatile methods for the functionalization of anthracene and higher acenes, producing

functionalized polyaromatic compounds that are not readily accessible by conventional methods.

ASSOCIATED CONTENT

Supporting Information

Experimental details and characterization of new compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

AUTHOR INFORMATION

Corresponding Author

* E-mail: nyoshikai@ntu.edu.sg

ACKNOWLEDGMENT

This work was supported by Singapore National Research Foundation (NRF-RF2009-05) and Nanyang Technological University.

REFERENCES

- (1) For selected recent reviews: (a) Arockiam, P. B.; Bruneau, C.; Dixneuf, P. H. *Chem. Rev.* **2012**, *112*, 5879. (b) Engle, K. M.; Mei, T.-S.; Wasa, M.; Yu, J.-Q. *Acc. Chem. Res.* **2012**, *45*, 788. (c) Ackermann, L. *Chem. Rev.* **2011**, *111*, 1315. (d) Lyons, T. W.; Sanford, M. S. *Chem. Rev.* **2010**, *110*, 1147. (e) Colby, D. A.; Bergman, R. G.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 624.
- (2) (a) Yamaguchi, J.; Yamaguchi, A. D.; Itami, K. *Angew. Chem., Int. Ed.* **2012**, *51*, 8960. (b) Wencel-Delord, J.; Glorius, F. *Nat. Chem.* **2013**, *5*, 369.
- (3) (a) Wang, C.; Dong, H.; Hu, W.; Liu, Y.; Zhu, D. *Chem. Rev.* **2012**, *112*, 2208. (b) Anthony, J. E. *Angew. Chem., Int. Ed.* **2008**, *47*, 452. (c) Anthony, J. E. *Chem. Rev.* **2006**, *106*, 5028. (d) Bendikov, M.; Wudl, F.; Perepichka, D. F. *Chem. Rev.* **2004**, *104*, 4891.
- (4) (a) Teraoka, T.; Hiroto, S.; Shinokubo, H. *Org. Lett.* **2011**, *13*, 2532. (b) Nakazono, S.; Easwaramoorthi, S.; Kim, D.; Shinokubo, H.; Osuka, A. *Org. Lett.* **2009**, *11*, 5426. (c) Nakazono, S.; Imazaki, Y.; Yoo, H.; Yang, J.; Sasamori, T.; Tokito, N.; Cedric, T.; Kageyama, H.; Kim, D.; Shinokubo, H.; Osuka, A. *Chem. Eur. J.* **2009**, *15*, 7530. (d) Matsumura, D.; Kitazawa, K.; Terai, S.; Kochi, T.; Le, Y.; Nitani, M.; Aso, Y.; Kakiuchi, F. *Org. Lett.* **2012**, *14*, 3882. (e) Kitazawa, K.; Kochi, T.; Sato, M.; Kakiuchi, F. *Org. Lett.* **2009**, *11*, 1951.
- (5) (a) Satoh, T.; Miura, M. *Chem. Eur. J.* **2010**, *16*, 11212. (b) Song, G.; Wang, F.; Li, X. *Chem. Soc. Rev.* **2012**, *41*, 3651. (c) Colby, D. A.; Tsai, A. S.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2012**, *45*, 814. (d) Patureau, F. W.; Wencel-Delord, J.; Glorius, F. *Aldrichimica Acta* **2012**, *45*, 31.
- (6) (a) Ueura, K.; Satoh, T.; Miura, M. *Org. Lett.* **2007**, *9*, 1407. (b) Mochida, S.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2010**, *12*, 5776.
- (7) Patureau, F. W.; Glorius, F. *J. Am. Chem. Soc.* **2010**, *132*, 9982.
- (8) Patureau, F. W.; Besset, T.; Glorius, F. *Angew. Chem., Int. Ed.* **2011**, *50*, 1064.
- (9) (a) Wang, F.; Song, G.; Li, X. *Org. Lett.* **2010**, *12*, 5430. (b) Rakshit, S.; Grohmann, C.; Besset, T.; Glorius, F. *J. Am. Chem. Soc.* **2011**, *133*, 2350.
- (10) Park, S. H.; Kim, J. Y.; Chang, S. *Org. Lett.* **2011**, *13*, 2372.
- (11) Tsai, A. S.; Brasse, M.; Bergman, R. G.; Ellman, J. A. *Org. Lett.* **2011**, *13*, 540.
- (12) (a) Feng, C.; Loh, T.-P. *Chem. Commun.* **2011**, *47*, 10458. (b) Gong, T.-J.; Xiao, B.; Liu, Z.-J.; Wan, J.; Xu, J.; Luo, D.-F.; Fu, Y.; Liu, L. *Org. Lett.* **2011**, *13*, 3235.
- (13) Aryl oxazolines: (a) Schröder, N.; Besset, T.; Glorius, F. *Adv. Synth. Catal.* **2012**, *354*, 579. Aryl triazenes: (b) Wang, C.; Chen, H.; Wang, Z.; Chen, J.; Huang, Y. *Angew. Chem., Int. Ed.* **2012**, *51*, 7242. Azomethine ylides: (c) Zhen, W.; Wang, F.; Zhao, M.; Du, Z.; Li, X. *Angew. Chem., Int. Ed.* **2012**, *51*, 11819. Isoquinolones: (d) Zhao, P.; Niu, R.; Wang, F.; Han, K.; Li, X. *Org. Lett.* **2012**, *14*, 4166. Arylphosphorus compounds: (e) Unoh, Y.; Hashimoto, Y.; Takeda, D.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2013**, *15*, 3258. (f) Chary, B. C.; Kim, S. *Org. Biomol. Chem.* **2013**, *11*, 6879. (g) Ryu, T.; Kim, J.; Park, Y.; Kim, S.; Lee, P. H. *Org. Lett.* **2013**, *15*, 3986. (h) Zhao, D.; Nimphius, C.; Lindale, M.; Glorius, F. *Org. Lett.* **2013**, *15*, 4504. Arylamine N-oxides: (i) Huang, X.; Huang, J.; Du, C.; Zhang, X.; Song, F.; You, J. *Angew. Chem., Int. Ed.* **2013**, *52*, 12970. Acylsilanes: (j) Becker, P.; Priebbenow, D. L.; Pirwerdjan, R.; Bolm, C. *Angew. Chem., Int. Ed.* **2014**, *53*, 269. Aryl sulfoxides: (k) Nobushige, K.; Hirano, K.; Satoh, T.; Miura, M. *Org. Lett.* **2014**, *16*, 1188.
- (14) (a) Mochida, S.; Shimizu, M.; Hirano, K.; Satoh, T.; Miura, M. *Chem. Asian J.* **2010**, *5*, 847. (b) Wang, F.; Song, G.; Du, Z.; Li, X. *J. Org. Chem.* **2011**, *76*, 2926. (c) Li, X.; Gong, X.; Zhao, M.; Song, G.; Deng, J.; Li, X. *Org. Lett.* **2011**, *13*, 5808. (d) Tan, X.; Liu, B.; Li, X.; Li, B.; Xu, S.; Song, H.; Wang, B. *J. Am. Chem. Soc.* **2012**, *134*, 16163.
- (15) (a) Nandji, D.; Ghosh, D.; Chen, S.-J.; Kuo, B.-C.; Wang, N. M.; Lee, H. M. *J. Org. Chem.* **2013**, *78*, 3445. (b) Pham, M. V.; Cramer, N. *Angew. Chem., Int. Ed.* **2014**, *53*, 3484.
- (16) (a) Lee, P.-S.; Yoshikai, N. *Angew. Chem., Int. Ed.* **2013**, *52*, 1240. (b) Dong, J.; Lee, P.-S.; Yoshikai, N. *Chem. Lett.* **2013**, *42*, 1140.
- (17) Gao, K.; Yoshikai, N. *Acc. Chem. Res.* **2014**, *47*, 1208.
- (18) Addition of CsOAc to the reaction of **1a** and **2a** had a detrimental effect (52% yield). We consider that the amide oxygen serves as an effective directing group for C–H activation without deprotonation.