OL | Organic Letters

pubs.acs.org/OrgLett Letter

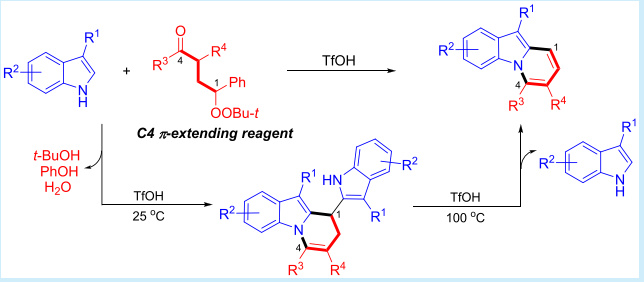
Annulative π-Extension (APEX) of Indoles to Pyrido[1,2-*a*]indoles Using 4-Oxo Peroxides as C4 Units

Xin Wang, Chenhao Lou, Leiyang Lv,* and Zhiping Li*

Cite This: *Org. Lett.* 2021, 23, 5978–5982 Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Annulative π-extension (APEX) of 3-substituted indoles to pyrido[1,2-*a*]indoles is developed by using 4-oxo peroxides as π-extending reagents, which are employed as versatile C4 building blocks. This transformation is initiated by Brønsted acid-mediated Hock rearrangement of the peroxyl group. Notably, the pyrido[1,2-*a*]indole products are obtained by elimination of the indole moiety from the corresponding dihydropyrido[1,2-*a*]indoles, which could be selectively formed at room temperature.



Nitrogen-fused heterocycles are important structural units prevalently found in the field of medicinal chemistry and material chemistry.[1] Pyrido[1,2-*a*]indoles are known for officinal candidates that possess a wide spectrum of pharmaceutical activities[2] and as building blocks to construct various organic materials.[3] Owing to their significant applications, various strategies have been developed to synthesize such pyrido[1,2-*a*]indole motifs (Scheme 1). The established methods have been mainly focused on the construction of heteroatomic skeleton, that is, pyrrole ring B[4] or pyridine ring C[5] (Scheme 1a). As is well-known, annulative π-extension (APEX)[6] enables rapid access to fused aromatic molecules from simple aromatic compounds in one step (Scheme 1b), state-of-the-art APEX transformation of indoles represents the most appealing approach for the synthesis of pyrido[1,2-*a*]indoles from the viewpoint of step-economy and availability of starting materials (Scheme 1c). In this context, several π-extending reagents such as diazoenal,[7] *ortho*-haloarylalkyne,[8] alkyne,[9] etc. have been developed to build such valuable scaffolds in the presence of metal catalysts. However, the associated metal residues limit their application in the pharmaceutical field. Therefore, further improvements in terms of reaction sustainability, diversity, and especially developing new π-extending reagents are highly desirable.

A series of cyclocondensations of heteroarenes with 1,4-dicarbonyl compounds have been established for the annulative π-extension.[10] However, this protocol failed to gain popularity due to the low selectivity and efficiency. Recently, we have reported that 4-oxo *tert*-butyl peroxides[11] acted as versatile C4 building blocks for the selective synthesis of furans,[12] pyrroles, as well as indoles via Brønsted acid-catalyzed Hock rearrangement of the peroxy group.[13] Continuing with our interest in the manipulations of organoperoxides, we envisioned that APEX reactions of 3-substituted indoles with 4-oxo peroxides may enable the synthesis of analogous π-extended pyrido[1,2-*a*]indoles in one step. Herein, we report our efforts in the APEX of indoles to prepare pyrido[1,2-*a*]indoles (Scheme 1d).

We initiated the study by investigating the reaction of 3-methyl-1*H*-indole **1a** and 4-oxo peroxide **2a** to optimize the reaction conditions (Table 1). Initially, the desired pyrido[1,2-*a*]indole product **3a** was not observed at 25 °C; instead, an unexpected dihydropyrido[1,2-*a*]indole **4a** was obtained in 16% yield in the presence of 0.5 equiv of TfOH (entry 1). The structure of **4a** was established by NMR spectroscopy and confirmed by single-crystal X-ray analysis (Figure 1). The yields of **4a** were increased upon raising the loading of TfOH (entries 2 and 3). The product **4a** was obtained in 62% yield at 50 °C with 8% of **3a** formed (entry 4). Further elevating the reaction temperature to 85 °C resulted in the formation of **4a** and **3a** in 35% and 45% yields, respectively (entry 5). To ensure higher chemoselectivity, preparation of **4a** was preferred at 25 °C, although in moderate yield (48%). To our delight, increasing the amount of TfOH to 2.0 equiv and the reaction time to 3 h afforded the target product **3a** in 74% yield, with no **4a** detected (entry 6). Further increasing the loading of TfOH to 3.0 equiv did not improve the reaction efficiency (entry 7). It is worth noting that **3a** was obtained in 76% yield with 3.0 equiv of **1a** and 2.0 or 3.0 equiv of TfOH under 100 °C for 5 h (entries 8 and 9). Lewis acid such as $BF_3{\cdot}OEt_2$ afforded **3a** in 49% yield (entry 10), while the reaction was

Received: June 20, 2021
Published: July 15, 2021

https://doi.org/10.1021/acs.orglett.1c02062
Org. Lett. 2021, 23, 5978–5982

Scheme 1. Synthetic Strategies for the Pyrido[1,2-*a*]indoles

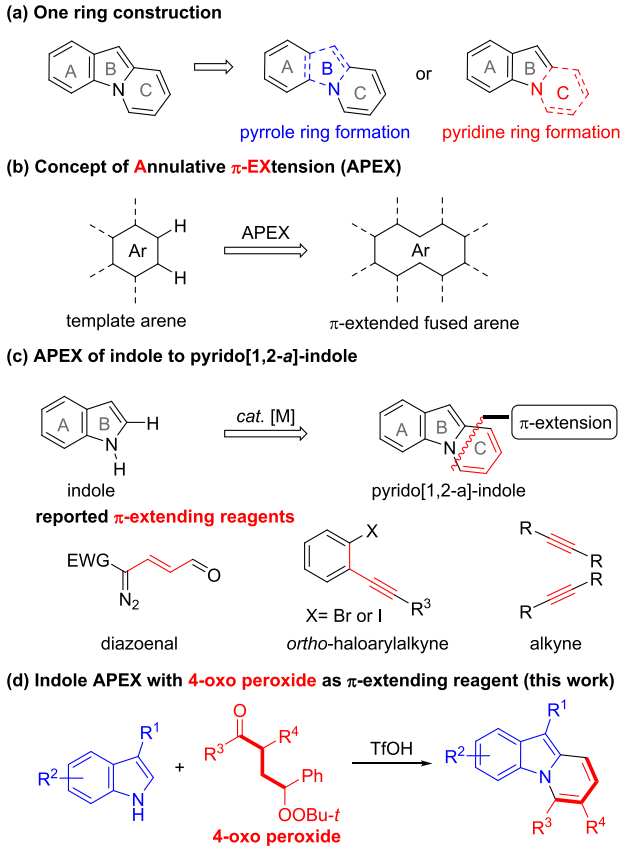
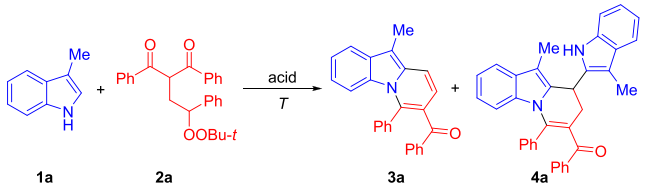


Table 1. Optimization of the Reaction Conditions[a]



entry	acid	*T* (°C)	**3a** (%)[b]	**4a** (%)[b]
1	TfOH (0.5 equiv)	25	N.D.	16
2	TfOH (1.0 equiv)	25	N.D.	30
3	TfOH (1.5 equiv)	25	N.D.	48
4	TfOH (1.5 equiv)	50	8	62
5	TfOH (1.5 equiv)	85	45	35
6[c]	TfOH (2.0 equiv)	85	74	N.D.
7[c]	TfOH (3.0 equiv)	85	74	N.D.
8[d]	TfOH (2.0 equiv)	100	76	N.D.
9[d]	TfOH (3.0 equiv)	100	76	N.D.
10	BF_3·OEt_2 (2.0 equiv)	100	49	N.D.
11	$FeCl_3$ (2.0 equiv)	100	N.D.	N.D.

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (0.1 mmol), MeCN (2.0 mL), 24 h, under air, unless otherwise noted. [b]Reported yields were based on **2a** and determined by ^{1}H NMR using CH_2Br_2 as internal standard. [c]**1a** (0.3 mmol), 3 h. [d]**1a** (0.3 mmol), 5 h.

messy and neither **3a** nor **4a** was detected in the case of $FeCl_3$ (entry 11).

With the optimal reaction conditions in hand, we then evaluated the reaction scope (Schemes 2 and 3). First, the preparation of diverse pyrido[1,2-*a*]indole derivatives was investigated (Scheme 2). A variety of 3-substituted indoles **1**

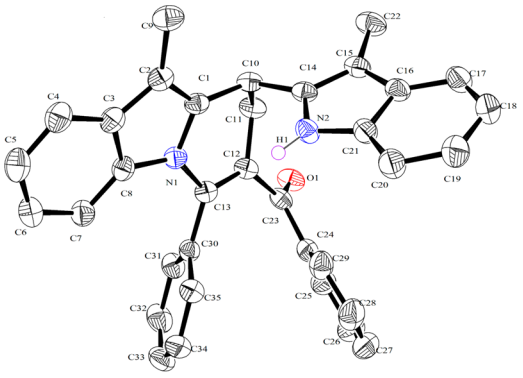
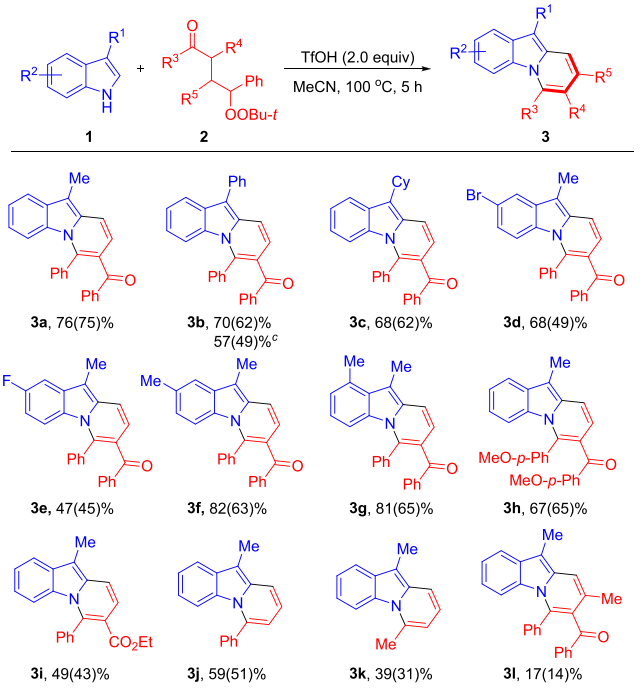


Figure 1. X-ray diffraction of **4a**. Thermal ellipsoids are at the 50% probability level.

Scheme 2. Synthesis of Pyrido[1,2-*a*]indoles 3[a,b]



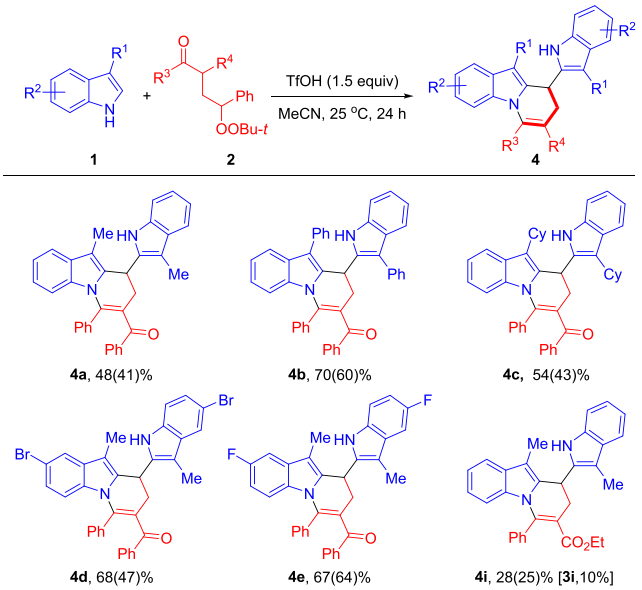
[a]Reaction conditions: **1** (0.3 mmol), **2** (0.1 mmol), TfOH (0.2 mmol), MeCN (2.0 mL), 100 °C, 5 h, under air. [b]Reported yields were based on **2** and determined by ^{1}H NMR using an internal standard; isolated ones were given in parentheses. [c]Reactions were carried out in 1.0 mmol.

reacted smoothly with **2a** to give the pyrido[1,2-*a*]indole products **3a**−**3g** in 47−82% yields, indicating that the 4-oxo peroxide **2a** plays as an efficient C4 π-extending reagent. When the reaction was carried out in 1.0 mmol, **3b** was obtained in 57% yield. It should be noted that electron-rich indoles are more favorable in the current APEX reaction (**3f** and **3g**). Peroxide derived from *β*-keto ester also reacted with **1a** to give the corresponding product **3i**. Importantly, monosubstituted (**3j** and **3k**) and trisubstituted (**3l**) annulation products were synthesized by application of the corresponding 4-oxo peroxide **2**, albeit in relatively lower yields. We hypothesized that the two former ones (**3j** and **3k**) are due to the electronic effect, yet the exact reason for the latter (**3l**) is unclear at the current stage.

Next, we explored the chemodivergent formation of the dihydropyrido[1,2-*a*]indole products **4** in the presence of 1.5

https://doi.org/10.1021/acs.orglett.1c02062
Org. Lett. 2021, 23, 5978−5982

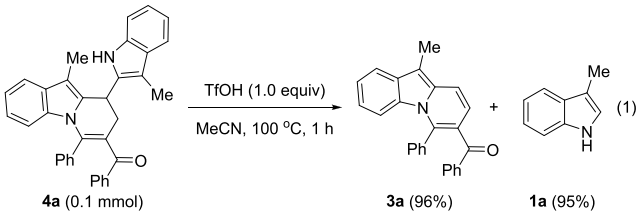
Scheme 3. Synthesis of Dihydropyrido[1,2-*a*]indole 4[a,b]



[a]Reaction conditions: **1** (0.5 mmol), **2** (0.1 mmol), TfOH (0.15 mmol), solvent (2.0 mL), 25 °C, 24 h, under air. [b]Reported yields were based on **2** and determined by ^{1}H NMR using an internal standard; isolated ones were given in parentheses.

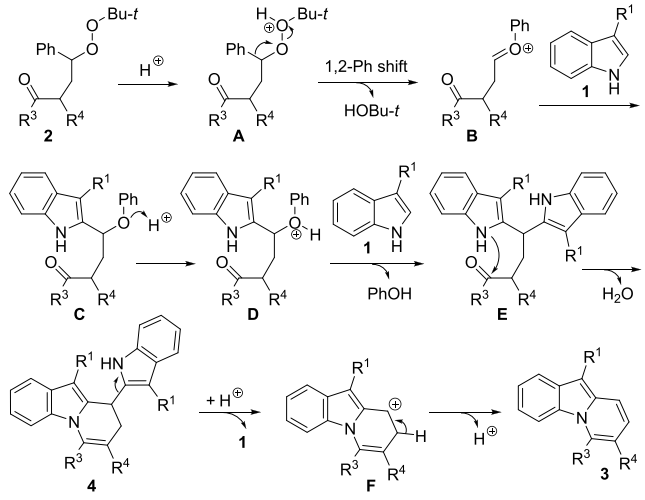
equiv of TfOH at 25 °C (Scheme 3). To our delight, **4a**–**4e** were obtained selectively under the standard conditions in moderate to good yields. In contrast, **4i** was obtained in 28% yield along with 10% of **3i** when peroxide that derived from *β*-keto ester was tested with **1a** under the same reaction conditions.

A control experiment was carried out to gain the relationship between dihydropyrido[1,2-*a*]indole **4** and pyrido[1,2-*a*]-indole **3**. For example, when **4a** was treated with TfOH (1.0 equiv) in 100 °C for 1 h, both **3a** and 3-methyl-1*H*-indole **1a** were obtained almost quantitatively (eq 1). This result clearly demonstrates that the annulative *π*-extension product **3** is formed via decomposition of the corresponding dihydropyrido[1,2-*a*]indole **4**.



On the basis of the above experiment and literature reports,[11−13] a tentative mechanism was proposed (Scheme 4). Initially, the protonation of the peroxide **2** gives the intermediate **A**, which undergoes the Hock rearrangement (1,2-migration of the phenyl group) to generate the key oxonium intermediate **B**. Then addition of electron-rich **1a** toward **B** generates the intermediate **C**, which is protonated and substituted by another molecule of indole to form intermediate **E**. Subsequent intramolecular cyclocondensation of **E** delivers the dihydropyrido[1,2-*a*]indole product **4**. Finally, high temperature (100 °C) and acid[14] facilitate **4** to rearomatize to afford the pyrido[1,2-*a*]indole product **3** through intermediate **F** by release of **1**.

Scheme 4. A Tentative Reaction Mechanism



In conclusion, we have demonstrated 4-oxo *tert*-butyl peroxides as new C4 *π*-extending reagents in the acid mediated step-economy annulation of indoles to afford *N*-fused conjugated products. This chemodivergent transformation proceeded in a stepwise manner; that is, the dihydropyrido-[1,2-*a*]indoles could be isolated at 25 °C, which readily rearomatized to form the pyrido[1,2-*a*]indoles promoted via acid at high temperature by releasing the indole moiety.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.orglett.1c02062.

Detailed experimental procedures and compound characterization data, single-crystal X-ray structure of **4a**, and NMR spectra of all new compounds (PDF)

Accession Codes

CCDC 2083477 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.

■ AUTHOR INFORMATION

Corresponding Authors

Leiyang Lv − *Department of Chemistry, Renmin University of China, Beijing 100872, China;* orcid.org/0000-0002-2850-8952; Email: lvleiyang2008@ruc.edu.cn

Zhiping Li − *Department of Chemistry, Renmin University of China, Beijing 100872, China;* orcid.org/0000-0001-7987-279X; Email: zhipingli@ruc.edu.cn

Authors

Xin Wang − *Department of Chemistry, Renmin University of China, Beijing 100872, China*

Chenhao Lou − *Department of Chemistry, Renmin University of China, Beijing 100872, China*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.orglett.1c02062

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (22071266). The research was also supported by the Fundamental Research Funds for the Central Universities, and the Research Funds of Renmin University of China (21XNLG04).

■ REFERENCES

(1) (a) Hennessy, E. T.; Betley, T. A. Complex N-Heterocycle Synthesis *via* Iron-Catalyzed. *Science* **2013**, *340*, 591−595. (b) Cui, X.; Li, Y.; Bachmann, S.; Scalone, M.; Surkus, A.-E.; Junge, K.; Topf, C.; Beller, M. Synthesis and Characterization of Iron−Nitrogen-Doped Graphene/Core−Shell Catalysts: Efficient Oxidative Dehydrogenation of N-Heterocycles. *J. Am. Chem. Soc.* **2015**, *137*, 10652−10658. (c) Chakraborty, S.; Brennessel, W. W.; Jones, W. D. A Molecular Iron Catalyst for the Acceptorless Dehydrogenation and Hydrogenation of N-Heterocycles. *J. Am. Chem. Soc.* **2014**, *136*, 8564−8567.

(2) (a) Ewing, J.; Hughes, G. K.; Ritchie, E.; Taylor, W. C. An Alkaloid Related to Dehydrolaudanosoline. *Nature* **1952**, *169*, 618−619. (b) Anderson, W. K.; Heider, A. R.; Raju, N.; Yucht, J. A. Vinylogous Carbinolamine Tumor Inhibitors. 23. Synthesis and Antileukemic Activity of Bis[[(carbamoyl)oxy]methyl]-substituted Pyrrolo[2,1-*a*]isoquinolines, Pyrrolo[1,2-*a*]quinolines, Pyrrolo[2,1-*a*]isobenzazepines, and Pyrrolo[1,2-*a*]benzazepines. *J. Med. Chem.* **1988**, *31*, 2097−2102. (c) Kanchanapoom, T.; Kasai, R.; Chumsri, P.; Hiraga, Y.; Yamasaki, K. Canthin-6-one and *β*-Carboline Alkaloids from Eurycoma Harmandiana. *Phytochemistry* **2001**, *56*, 383−386. (d) Mizutani, M.; Inagaki, F.; Nakanishi, T.; Yanagihara, C.; Tamai, I.; Mukai, C. Total Syntheses of (−)- and (+)-Goniomitine. *Org. Lett.* **2011**, *13*, 1796−1799.

(3) (a) Zhu, L.; Kim, E.-G.; Yi, Y.; Ahmed, E.; Jenekhe, S. A.; Coropceanu, V.; Brédas, J.-L. Charge-Transport Properties of the Tetraphenylbis(indolo[1,2-*a*])quinoline and 5,7-Diphenylindolo[1,2-a]quinoline Crystals. *J. Phys. Chem. C* **2010**, *114*, 20401−20409. (b) Ahmed, E.; Briseno, A. L.; Xia, Y.; Jenekhe, S. A. High Mobility Single-Crystal Field-Effect Transistors from Bisindoloquinoline Semiconductors. *J. Am. Chem. Soc.* **2008**, *130*, 1118−1119.

(4) (a) Karthikeyan, I.; Arunprasath, D.; Sekar, G. An Efficient Synthesis of Pyrido[1,2-*a*]indoles through Aza-Nazarov Type Cyclization. *Chem. Commun.* **2015**, *51*, 1701−1704. (b) Zhang, T. S.; Zhao, Q.; Hao, W. J.; Tu, S. J.; Jiang, B. Cu-Catalyzed [4 + 1] Annulation toward Indolo[2,1-*a*]isoquinolines through Oxidative $C(sp^3)/C(sp^2)$-H Bond Bifunctionalization. *Chem. - Asian J.* **2019**, *14*, 1042−1049. (c) Rawat, D.; Ravi, C.; Joshi, A.; Suresh, E.; Jana, K.; Ganguly, B.; Adimurthy, S. Indium-Catalyzed Denitrogenative Transannulation of Pyridotriazoles: Synthesis of Pyrido[1,2- *a*]-indoles. *Org. Lett.* **2019**, *21*, 2043−2047. (d) Kraus, G. A.; Gupta, V.; Kohut, M.; Singh, N. A Direct Synthesis of 5,6-Dihydroindolo[2,1-*a*]isoquinolines that Exhibit Immunosuppressive Activity. *Bioorg. Med. Chem. Lett.* **2009**, *19*, 5539−42. (e) Karthikeyan, I.; Sekar, G. Iron-Catalyzed C-H Bond Functionalization for the Exclusive Synthesis of Pyrido[1,2-*a*]indoles or Triarylmethanols. *Eur. J. Org. Chem.* **2014**, *2014*, 8055−8063. (f) Gasonoo, M.; Naredla, R. R.; Nilsson Lill, S. O.; Klumpp, D. A. Tetra- and Pentacationic Electrophiles and Their Chemistry. *J. Org. Chem.* **2016**, *81*, 11758−11765. (g) Kennedy, S. H.; Gasonoo, M.; Klumpp, D. A. Superelectrophilic Carbocations: Preparation and Reactions of a Substrate with Six Ionizable Groups. *Beilstein J. Org. Chem.* **2019**, *15*, 1515−1520. (h) Rogness, D. C.; Markina, N. A.; Waldo, J. P.; Larock, R. C. Synthesis of Pyrido[1,2-*a*]indole Malonates and Amines through Aryne Annulation. *J. Org. Chem.* **2012**, *77*, 2743−2755.

(5) (a) Morimoto, K.; Hirano, K.; Satoh, T.; Miura, M. Rhodium-Catalyzed Oxidative Coupling/Cyclization of 2-Phenylindoles with Alkynes via C-H and N-H Bond Cleavages with Air as the Oxidant. *Org. Lett.* **2010**, *12*, 2068−2071. (b) Xia, Y. Q.; Dong, L. Ruthenium(II)-Catalyzed Indolo[2,1-*a*]isoquinolines Synthesis by Tandem C-H Allylation and Oxidative Cyclization of 2-Phenylindoles with Allyl Carbonates. *Org. Lett.* **2017**, *19*, 2258−2261. (c) Obata, A.; Sasagawa, A.; Yamazaki, K.; Ano, Y.; Chatani, N. Nickel-Catalyzed Oxidative C-H/N-H Annulation of N-heteroaromatic Compounds with Alkynes. *Chem. Sci.* **2019**, *10*, 3242−3248. (d) Liu, Y.; Yang, Z.; Chauvin, R.; Fu, W.; Yao, Z.; Wang, L.; Cui, X. One-Pot Synthesis of Furo[3,4-*c*]indolo[2,1-*a*]isoquinolines through Rh(III)-Catalyzed Cascade Reactions of 2-Phenylindoles with 4-Hydroxy-2-alkynoates. *Org. Lett.* **2020**, *22*, 5140−5144. (e) Thavaselvan, S.; Parthasarathy, K. Nickel-Catalyzed Cyclization Strategy for the Synthesis of Pyrroloquinolines, Indoloquinolines, and Indoloisoquinolines. *Org. Lett.* **2020**, *22*, 3810−3814. (f) Cai, Q.; Li, Z.; Wei, J.; Fu, L.; Ha, C.; Pei, D.; Ding, K. Synthesis of Aza-Fused Polycyclic Quinolines through Copper-Catalyzed Cascade Reactions. *Org. Lett.* **2010**, *12*, 1500−1503. (g) Hulcoop, D. G.; Lautens, M. Palladium-Catalyzed Annulation of Aryl Heterocycles with Strained Alkenes. *Org. Lett.* **2007**, *9*, 1761−1764. (h) Gericke, K. M.; Chai, D. I.; Lautens, M. The Versatile Role of Norbornene in C-H Functionalization Processes: Concise Synthesis of Tetracyclic Fused Pyrroles *via* a Threefold Domino Reaction. *Tetrahedron* **2008**, *64*, 6002−6014. (i) Liu, X.; Li, X.; Liu, H.; Guo, Q.; Lan, J.; Wang, R.; You, J. Aldehyde as a Traceless Directing Group for Rh(III)-Catalyzed C-H Activation: A Facile Access to Diverse Indolo[1,2-a]quinolines. *Org. Lett.* **2015**, *17*, 2936−2939. (j) Qi, S. L.; Li, Y.; Li, J. F.; Zhang, T.; Luan, Y. X.; Ye, M. Ni-Catalyzed Dual C-H Annulation of Benzimidazoles with Alkynes for Synthesis of pi-Extended Heteroarenes. *Org. Lett.* **2021**, *23*, 4034−4039.

(6) (a) Ito, H.; Ozaki, K.; Itami, K. Annulative pi-Extension (APEX): Rapid Access to Fused Arenes, Heteroarenes, and Nanographenes. *Angew. Chem., Int. Ed.* **2017**, *56*, 11144−11164. (b) Kawahara, K. P.; Matsuoka, W.; Ito, H.; Itami, K. Synthesis of Nitrogen-Containing Polyaromatics by Aza-Annulative pi-Extension of Unfunctionalized Aromatics. *Angew. Chem., Int. Ed.* **2020**, *59*, 6383−6388. (c) Qiao, Y.; Wu, X.-X.; Zhao, Y.; Sun, Y.; Li, B.; Chen, S. Copper-Catalyzed Successive C−C bond formations on Indoles or Pyrrole: A Convergent Synthesis of Symmetric and Unsymmetric Hydroxyl Substituted N-H Carbazoles. *Adv. Synth. Catal.* **2018**, *360*, 2138−2143. (d) Zeng, Z.; Jin, H.; Sekine, K.; Rudolph, M.; Rominger, F.; Hashmi, A. S. K. Gold-Catalyzed Regiospecific C-H Annulation of o-Ethynylbiaryls with Anthranils: pi-Extension by Ring-Expansion En Route to N-Doped PAHs. *Angew. Chem., Int. Ed.* **2018**, *57*, 6935−6939. (e) Gu, Y.; Huang, W.; Chen, S.; Wang, X. Bismuth(III) Triflate Catalyzed Three-Component Reactions of Indoles, Ketones, and alpha-Bromoacetaldehyde Acetals Enable Indole-to-Carbazole Transformation. *Org. Lett.* **2018**, *20*, 4285−4289. (f) Jiang, Z.; Zhou, J.; Zhu, H.; Liu, H.; Zhou, Y. Rh(III)-Catalyzed [5 + 1] Annulation of Indole-enaminones with Diazo Compounds to Form Highly Functionalized Carbazoles. *Org. Lett.* **2021**, *23*, 4406−4410.

(7) (a) Dawande, S. G.; Kanchupalli, V.; Kalepu, J.; Chennamsetti, H.; Lad, B. S.; Katukojvala, S. Rhodium Enalcarbenoids: Direct Synthesis of Indoles by Rhodium(II)-Catalyzed [4 + 2] Benzannulation of Pyrroles. *Angew. Chem., Int. Ed.* **2014**, *53*, 4076−4080. (b) Rathore, K. S.; Harode, M.; Katukojvala, S. Regioselective pi-extension of indoles with rhodium enalcarbenoids–synthesis of substituted carbazoles. *Org. Biomol. Chem.* **2014**, *12*, 8641−8645. (c) Dawande, S. G.; Lad, B. S.; Prajapati, S.; Katukojvala, S. Rhodium-Catalyzed Pyridannulation of Indoles with Diazoenals: a Direct Approach to Pyrido[1,2-*a*]indoles. *Org. Biomol. Chem.* **2016**, *14*, 5569−5573.

(8) (a) Verma, A. K.; Kesharwani, T.; Singh, J.; Tandon, V.; Larock, R. C. A Copper-Catalyzed Tandem Synthesis of Indolo- and Pyrrolo[2,1-*a*]isoquinolines. *Angew. Chem., Int. Ed.* **2009**, *48*, 1138−1143. (b) Verma, A. K.; Jha, R. R.; Chaudhary, R.; Tiwari, R. K.; Reddy, K. S.; Danodia, A. Copper-catalyzed Tandem Synthesis of Indolo-, Pyrrolo[2,1-*a*]isoquinolines, Naphthyridines and Bisindolo/

https://doi.org/10.1021/acs.orglett.1c02062
Org. Lett. 2021, 23, 5978−5982

pyrrolo[2,1-*a*]isoquinolines *via* Hydroamination of *ortho*-Haloarylalkynes Followed by C-2 Arylation. *J. Org. Chem.* **2012**, *77*, 8191−8205. (c) Jha, R. R.; Danodia, A. K.; Verma, A. K. Synthesis of Fused Heterocycles *via* Preferential Hydroamination of *o*-Haloarylalkynes over N-arylation and Successive Intramolecular C-C Bond Formation. *Tetrahedron Lett.* **2014**, *55*, 4724−4730.

(9) Samala, S.; Pallavi, P.; Kumar, R.; Arigela, R. K.; Singh, G.; Ampapathi, R. S.; Priya, A.; Datta, S.; Patra, A.; Kundu, B. One-pot Synthesis of Highly Fluorescent Pyrido[1,2-*a*]indole Derivatives through C-H/N-H Activation: Photophysical Investigations and Application in Cell Imaging. *Chem. - Eur. J.* **2014**, *20*, 14344−14350.

(10) (a) Fletcher, H. 1,3,4,7-Substituted Isoindoles and Isoindolenines. *Tetrahedron* **1966**, *22*, 2481−2486. (b) Cranwell, P. A.; Saxton, J. E. 683. A Synthesis of Ellipticine. *J. Chem. Soc.* **1962**, 3482−3487. (c) Miller, C. M.; McCarthy, F. O. Isolation, Biological Activity and Synthesis of the Natural Product Ellipticine and Related Pyridocarbazoles. *RSC Adv.* **2012**, *2*, 8883−8918.

(11) (a) Schweitzer-Chaput, B.; Demaerel, J.; Engler, H.; Klussmann, M. Acid-Catalyzed Oxidative Radical Addition of Ketones to Olefins. *Angew. Chem., Int. Ed.* **2014**, *53*, 8737−8740. (b) Lu, S.; Qi, L.; Li, Z. Cobalt-Catalyzed Alkylation-Peroxidation of Alkenes with 1,3-Dicarbonyl Compounds and T-Hydro. *Asian J. Org. Chem.* **2017**, *6*, 313−321.

(12) Zheng, X.; Lu, S.; Li, Z. The Rearrangement of *tert*-Butylperoxides for the Construction of Polysubstituted Furans. *Org. Lett.* **2013**, *15*, 5432−5435.

(13) (a) Zheng, X.; Lv, L.; Lu, S.; Wang, W.; Li, Z. Benzannulation of Indoles to Carbazoles and Its Applications for Syntheses of Carbazole Alkaloids. *Org. Lett.* **2014**, *16*, 5156−5159. (b) Lu, S.; Xu, R.; Li, Z. Benzannulation of Pyrroles to 4,5-Disubstituted Indoles through Brønsted-Acid-Promoted Rearrangement of *tert*-Butyl Peroxides. *Asian J. Org. Chem.* **2017**, *6*, 1604−1611.

(14) (a) Li, H.; Yang, J.; Liu, Y.; Li, Y. Iron-Catalyzed Cascade Arene-Aldehyde Addition/Cyclizations for the Highly Efficient Synthesis of Xanthenes and Its Analogous: Observation of a C-C Bond Cleavage in Indole-Based Triarylmethanes. *J. Org. Chem.* **2009**, *74*, 6797−6801. (b) Roberts, R. M.; El-Khawaga, A. M.; Sweeney, K. M.; El-Zohry, M. F. *J. Org. Chem.* **1987**, *52*, 1591−1599.

https://doi.org/10.1021/acs.orglett.1c02062
Org. Lett. 2021, 23, 5978−5982