Organic LETTERS

Letter

Cite This: Org. Lett. XXXX, XXX, XXX−XXX

pubs.acs.org/OrgLett

In Situ Generation of Nitrile Oxides from NaCl−Oxone Oxidation of Various Aldoximes and Their 1,3-Dipolar Cycloaddition

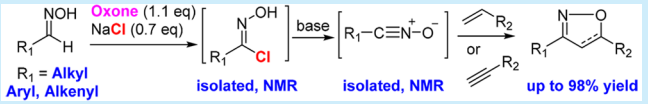
Guodong Zhao,[†] Lixin Liang,[†] Chi Ho Ethan Wen,[†] and Rongbiao Tong*[,†,‡]

[†]Department of Chemistry, The Hong Kong University of Science and Technology, Clearwater Bay, Kowloon, Hong Kong China

[‡]HKUST Shenzhen Research Institute, Shenzhen 518057, China

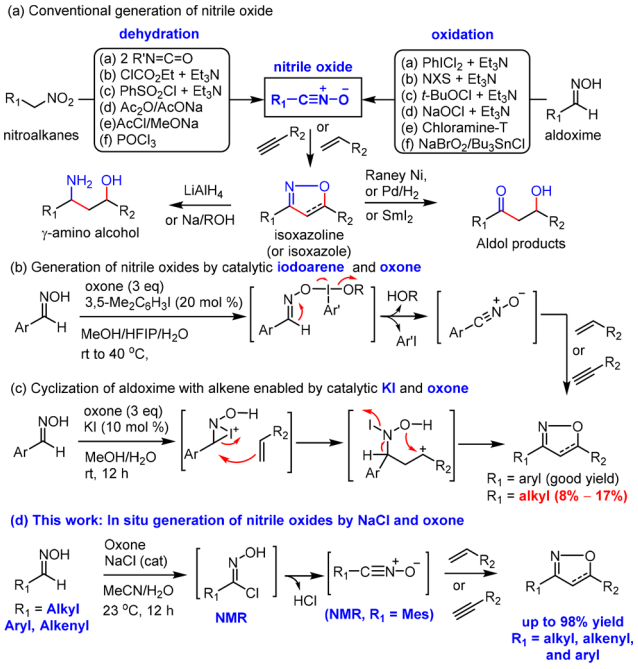
Supporting Information

ABSTRACT: Reported is a new green protocol for the efficient in situ generation of nitrile oxides through NaCl/Oxone oxidation of aldoximes and their dipolar cycloaddition. The key feature is the use of a green chemistry approach to address the substrate scope of aldoximes: broad scope (aliphatic, aromatic, and alkenyl aldoximes) without production of organic byproducts derived from oxidant and/or catalyst. Importantly, NaCl/Oxone-promoted three-component cycloaddition of aldehyde, hydroxylamine hydrochloride, and alkene was demonstrated to be competent (63−81%).



The 1,3-dipolar cycloaddition of nitrile oxides with various alkenes and alkynes is a powerful C−C/C−O bond-forming transformation to deliver five-membered heterocycles,[1−5] isoxazolines or isoxazoles, which are versatile precursors for β-hydroxy carbonyls and γ-amino alcohols in the chemical synthesis of (non)natural products.[6−10] Generation of the nitrile oxides is critical to this [3 + 2]-cycloaddition and often achieved by one of two strategies: dehydration of nitroalkanes[11−17] or oxidation of aldoximes[18,19] (Scheme 1a). The oxidative process has received much attention toward methodology development and more applications in total synthesis of complex molecules presumably because of the readily available aldoximes (condensation of aldehyde and hydroxylamine), mild and selective oxidation conditions, and tolerance of various functional groups. Many oxidants including *t*-BuOCl, *t*-BuOI, *m*-CPBA, $ArI(OAc)_2$, DMDO, NXS, NaClO, $NaBrO_2/Bu_3SnCl$, Chloramine-T, $PhICl_2$, MnO_2 ,and CrO_2 (Magtrieve) have been identified for efficient generation of nitrile oxides from aldoximes.[20−31] However, most oxidants either require in-house preparation (*t*-BuOI, *t*-BuOCl, and DMDO) or produce stoichiometric toxic organic byproducts (NCS, NBS, *m*-CPBA, and $ArI(OAc)_2$). From a green chemistry point of view, Oxone (triple salt of potassium peroxymonosulfate: $2KHSO_5−KHSO_4−K_2SO_4$) is an environmentally friendly, bench-stable, nontoxic, inorganic oxidant and, therefore, should be an ideal oxidant for aldoximes. Without surprise, Oxone was used as the terminal oxidant by Yoshimura, Zhdankin, and co-workers for oxidative cycloaddition of aldoximes and alkenes/alkynes through two intriguing mechanisms (Scheme 1b and 1c).[32,33] One major limitation of these two Oxone-based approaches is the poor yield (8%−17%) for the oxidative cycloaddition of aliphatic aldoximes. To address this limitation, we initiated our study and herein report our findings that NaCl/Oxone/Na_2CO_3 is a green and efficient catalytic system for in situ generation of both aromatic and aliphatic nitrile oxides for [3 + 2]-cycloaddition (Scheme 1d). Notably, NMR characterization of the isolated intermediates (hydroximoyl chloride and nitrile oxide) suggested that the mechanism was different from those proposed by Yoshimura and Zhdankin (Scheme 1b,c).

Scheme 1. Previous Methods and Our Method for Generation of Nitrile Oxides for [3 + 2]-Cycloaddition



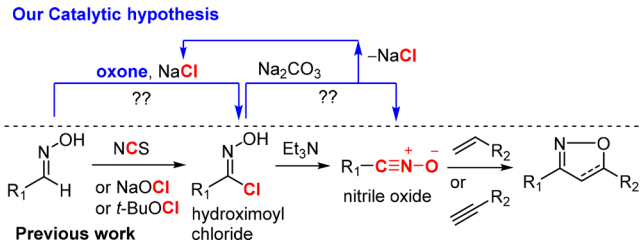
In continuation of our long-term program of green oxidation through exploitation of Oxone and halide with the ultimate goal of replacing NXS (or other halogenating agents: Cl_2, Br_2,

Received: November 30, 2018

DOI: 10.1021/acs.orglett.8b03829
Org. Lett. XXXX, XXX, XXX−XXX

t-BuOX, HOX, and others) in organic synthesis,[34−37] we were interested in exploring the replacement of the widely used NCS (or *t*-BuOCl) with Oxone/NaCl for the in situ generation of nitrile oxides from aldoximes (Scheme 2). We

Scheme 2. Our Hypothesis of Generation of Nitrile Oxide through Oxone/NaCl Oxidation of Aldoxime and HCl Elimination

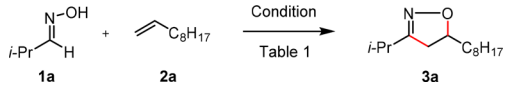


envisioned that aldoxime could be oxidized by Oxone and NaCl to provide the hydroximoyl chloride, and sodium carbonate may be used to replace Et_3N to effect the elimination of HCl to generate the nitrile oxide along with regeneration of NaCl as the catalyst. Obviously, the possible competitive dichlorination of alkene reported by our group using Oxone/NaCl[37] (in CH_2Cl_2−H_2O) was a concern, and different reaction conditions might be needed to point the reactivity toward the generation of nitrile oxides.

We chose aliphatic aldoxime **1a** and aliphatic alkene **2a** to examine our hypothesis (Table 1). Gratifyingly, our initial attempt was very positive: 32% yield of isoxazoline **3a** was detected by ^{1}H NMR when the MeOH/H_2O solution of **1a** and **2a** at rt was treated with Oxone (1.5 equiv), NaCl (0.1 equiv), and Na_2CO_3 (1.5 equiv) (Table 1, entry 1). Notably, no alkene dihalogenation was observed. Interestingly, we found that the use of NaBr, NaI, or KI as the catalyst also delivered the cycloaddition product **3a** with low yields (entries 2−4). The absence of sodium carbonate resulted in no generation of nitrile oxide but only hydroximoyl halide (entries 5−7). Further examination of different bases, solvents, and stoichiometry (entries 8−13) led us to identify the optimal conditions for the [3 + 2]-cycloaddition with 77% yield (entry 13). Intriguingly, chloride outperformed the corresponding bromide and iodide under otherwise identical conditions (entries 14 and 15).

With the optimized conditions in hand, we set out to examine the substrate scope of [3 + 2]-cycloaddition of aliphatic aldoximes with various types of alkenes and alkynes (Scheme 3). The in situ generated isopropyl nitrile oxide from isopropyl aldoxime can react with various terminal alkenes to provide isoxazolines with excellent yields. The regioselectivity was excellent (5-isomer for terminal alkene) and consistent with the general regioselectivity trend reported in the literature.[1−5,38] Notably, under these mild reaction conditions, a variety of functional groups survived, including electrophilic alkyl bromide (**3c** and **3d**), silyl ether (**3e** and **3j**), lactone (**3g**), and alcohol (**3k** and **3l**). The electron-rich alkene (**3i**), allyl silane (**3h**), aromatic alkenes (**3n**−**p**), electron-deficient acrylate (**3q**−**t**), acrylonitrile (**3u**), and enones (**3m**, **3v**,**w**)[38] were excellent substrates for the [3 + 2]-cycloaddition of this in situ generated aliphatic nitrile oxide. Other aliphatic aldoximes also reacted efficiently with alkenes to provide the isoxazolines in excellent overall yields (**3x**−**ae**). In addition, the cycloaddition of the aliphatic aldoxime with alkynes proceeded

Table 1. Optimization of Catalytic Cycloaddition of Aliphatic Aldoxime 1a with Aliphatic Alkene 2a[a]



1a **2a** **3a**

entry	MX (eq)	Oxone (equiv)	base (1.5 equiv)	solvent (v/v, 20/1)	yield[b] (%, **3a**)
1	NaCl (0.1)	1.5	Na_2CO_3	MeOH/H_2O	32
2	NaI (0.1)	1.5	Na_2CO_3	MeOH/H_2O	33
3	NaBr (0.1)	1.5	Na_2CO_3	MeOH/H_2O	28
4	KI (0.1)	1.5	Na_2CO_3	MeOH/H_2O	34
5	NaI (0.1)	1.5		MeOH/H_2O	0
6	NaBr (0.1)	1.5		MeOH/H_2O	0
7	NaCl (0.1)	1.5		MeOH/H_2O	0
8	NaCl (0.1)	1.5	$NaHCO_3$[c]	MeOH/H_2O	30
9	NaCl (0.1)	1.5	Cs_2CO_3	MeOH/H_2O	25
10	NaCl (1.1)	1.5	Na_2CO_3	MeOH/H_2O	66
11	NaCl (1.1)	1.5	Na_2CO_3	THF/H_2O	15
12	NaCl (1.1)	1.5	Na_2CO_3	MeCN/H_2O	77
13	**NaCl (0.7)**	**1.1**	**Na_2CO_3**	**MeCN/H_2O**	**77**
14	NaBr (0.7)	1.1	Na_2CO_3	MeCN/H_2O	65
15	NaI (0.7)	1.1	Na_2CO_3	MeCN/H_2O	46

[a]Conditions: To a solution of **1a** (0.2 mmol) and **2a** (0.26 mmol) in the solvents (1.0 mL) at room temperature were added Oxone, metal halide, and base and the reaction mixture was stirred for 12 h. [b]Yield was determined by ^{1}H NMR of the crude reaction mixture using CH_2Br_2 as the internal reference. [c]3.0 eq was added.

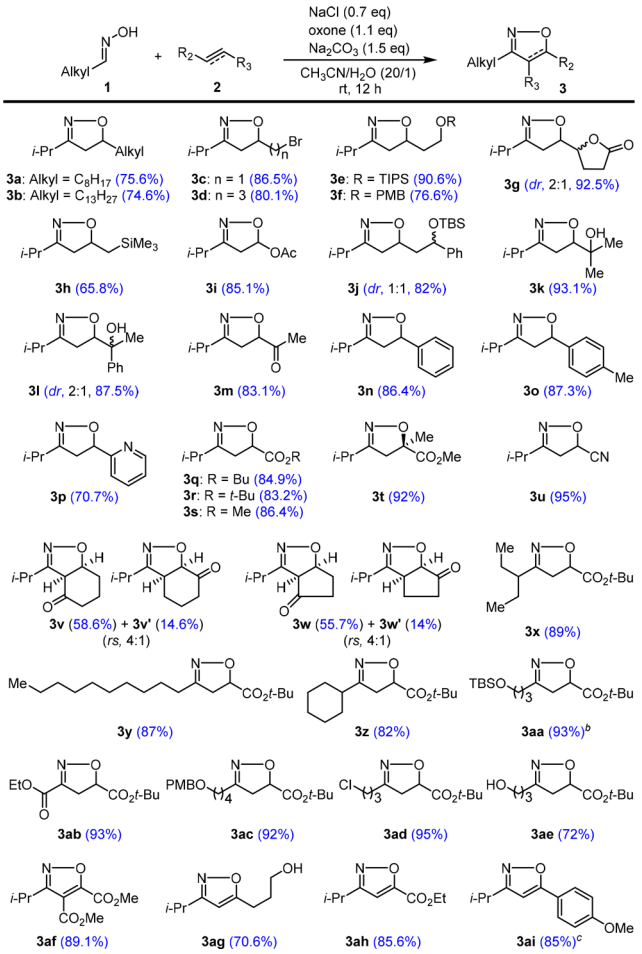
smoothly to provide the corresponding isoxazoles in excellent yield (**3af**−**ai**).

Next, we were interested in extending the aliphatic aldoximes to aromatic aldoximes for the oxidative cycloaddition. Gratifyingly, under our optimized standard condition, all examined aromatic aldoximes regardless of electronic and steric properties were competent substrates for oxidative cycloaddition with *tert*-butyl acrylate (Scheme 4). Notably, the heteroaromatic aldoximes (**3aq**−**as**) could be used under theses oxidation conditions for 1,3-dipolar cycloaddition, and we did not observe the oxidation of thiophene, furan, or pyridine (readily oxidized to be an *N*-oxide derivative).[39,40] Remarkably, conjugate aldoximes could also be employed under our conditions for the oxidative cycloaddition (**3at**−**av**). It was noted that alkynyl aldoxime was a poor substrate (**3aw**), which was the only type of aldoxime examined to give low yield. Nevertheless, the generality of the aldoxime scope was indeed remarkable and beyond our initial expectation of addressing the generation of nitrile oxides from aliphatic aldoximes.

Finally, we attempted to isolate and characterize the hypothetic intermediates hydroximoyl chloride and nitrile oxide in order to shed light on the underlying mechanism (Scheme 5). Oxidation of isopropyl aldoxime (**1a**) with Oxone and NaCl in the absence of sodium carbonate occurred within 2 h to provide isolable hydroximoyl chloride **4a** (90% yield),[41]

DOI: 10.1021/acs.orglett.8b03829
Org. Lett. XXXX, XXX, XXX−XXX

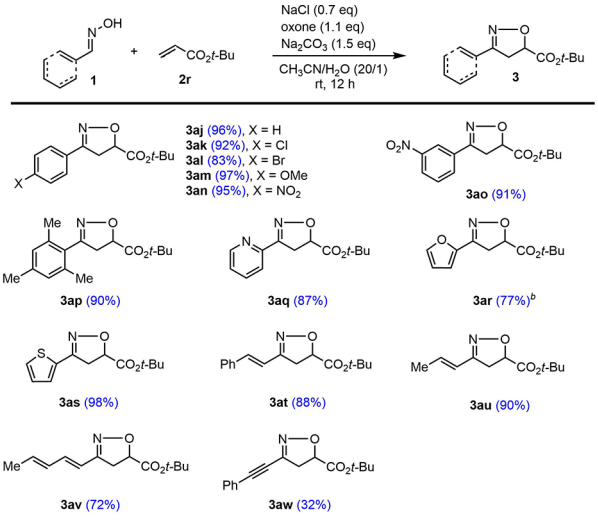
Scheme 3. Substrate Scope of Oxidative [3 + 2]-Cycloaddition of Aliphatic Aldoximes with Alkenes and Alkynes[a]



[a]Conditions: To a solution of **1** (0.46 mmol, 1.0 equiv) and **2** (0.6 mmol, 1.3 equiv) in $MeCN/H_2O$ (20/1, 2 mL) at room temperature were added Oxone (311 mg, 1.1 equiv), NaCl (18.8 mg, 0.7 equiv), and Na_2CO_3 (73.1 mg, 1.5 equiv) for 12 h. [b]$NaHCO_3$ (154.7 mg, 4.0 equiv) was used instead of Na_2CO_3, and the reaction time was 2 h. [c]Reaction time was 6 h.

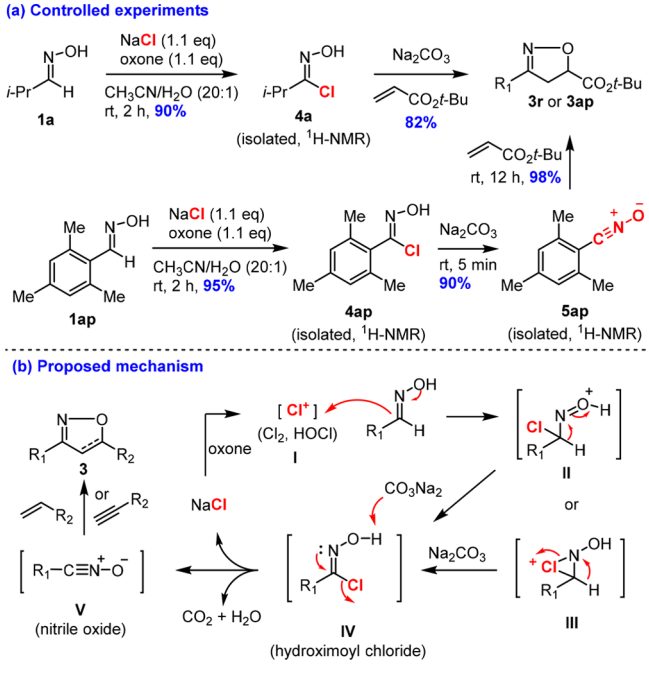
which was confirmed by ^1H NMR and then treated with sodium carbonate and *tert*-butyl acrylate to afford the cycloaddition adduct **3r** in 82% yield. Similarly, hydroximoyl chloride **4ap**[41] could be isolated in 95% yield from the base-free oxidation of mesityl aldoxime **1ap**. Remarkably, upon treatment of **4ap** with sodium carbonate the mesityl nitrile oxide (**5ap**)[42] was stable enough to be isolated for ^1H NMR spectral analysis and cycloaddition with *tert*-butyl acrylate. These findings allowed us to conclude that the oxidation of aldoximes with Oxone and NaCl provided the key intermediate hydroximoyl chloride, which upon treatment of base underwent HCl elimination to generate the nitrile oxide for the cycloaddition. Therefore, the detailed mechanism was proposed as depicted in Scheme 3b. Oxidation of chloride with Oxone would generate the chlorinating species **I** (Cl_2 or HOCl). Chlorination of the aldoxime might involve intermediate **II** or **III** to provide the hydroximoyl chloride **IV**. Sodium carbonate as a base would promote the HCl elimination to generate the nitrile oxide **V**, along with regeneration of chloride for Oxone oxidation in the next

Scheme 4. Oxidative [3 + 2]-Cycloaddition of Conjugate Aldoximes with *tert*-Butyl Acrylate[a]



[a]Conditions: To a solution of **1** (0.46 mmol) and **2r** (0.6 mmol) in $MeCN/H_2O$ (20/1, 2.0 mL) at room temperature were added Oxone (311 mg, 1.1 equiv), NaCl (18.8 mg, 0.7 equiv), and Na_2CO_3 (73.1 mg, 1.5 equiv) for 12 h. [b]$NaHCO_3$ (154.7 mg, 4 equiv) was used instead of Na_2CO_3, and the reaction time was 2 h.

Scheme 5. Isolation and Characterization of Hydroximoyl Chloride and Nitrile Oxide and Our Mechanistic Hypothesis



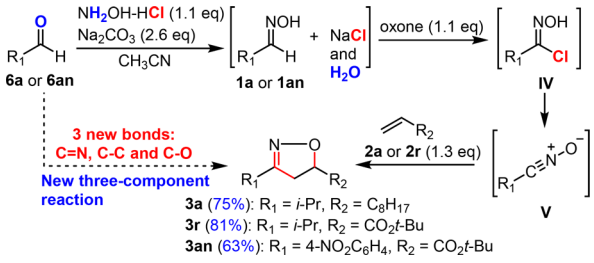
catalytic cycle. It is generally well accepted that the 1,3-dipolar cycloaddition of nitrile oxides with alkenes follows a concerted pathway to give isoxazolines (**V** → **3**).[43]

Finally, we decided to examine the possibility of combining the aldoxime formation and oxidative cycloaddition in a one-pot sequential manner. Guided by our mechanistic understanding, we conceived that NaCl generated as a byproduct in the condensation of aldehyde (**6a** or **6an**) and hydroxylamine hydrochloride can be used in the second step (cycloaddition)

DOI: 10.1021/acs.orglett.8b03829
Org. Lett. XXXX, XXX, XXX−XXX

as the catalyst for Oxone−NaCl oxidative cycloaddition (Scheme 6), while stoichiometric water from the condensation

Scheme 6. Three-Component Oxidation Reaction of Aldehyde, Hydroxylamine Hydrochloride, and Alkene



to aldoxime was beneficial for dissolving the Oxone or at least tolerated in the second step. To verify our hypothesis, we carried out the experiment by simply mixing the aldehyde (**6a** or **6an**), hydroxylamine hydrochloride, Na_2CO_3, Oxone, and the alkene (**2a** or **2r**) in CH_3CN in one flask, and the mixture was stirred vigorously for 12 h. To our delight, comparable high yields (63−81%) were obtained for all three representative examples (**3a**, **3r**, and **3an**). This was truly remarkable because it was (1) a new three-component reaction that formed three new bonds, C═N, C−C, and C−O, (2) a good example that a byproduct (NaCl) in the first step was fully utilized in the second step (one pot) as a catalyst or reagent, and (3) the greenest and most atom-economic [3 + 2]-cycloaddition of nitrile oxides with alkenes. It is expected that other aldehydes and alkenes could be used for this three-component oxidative cycloaddition with hydroxylamine−HCl.

In summary, we have developed a new green protocol for efficient in situ generation of nitrile oxides from Oxone/NaCl oxidation of aldoximes for 1,3-dipolar cycloaddition with different alkenes and alkynes. The key feature of this new method is the use of a green chemistry approach to address the substrate scope: broad scope (aliphatic, aromatic, alkenyl aldoximes) without generation of organic byproducts. The simple open-flask operation, low-cost and nontoxic reagents, and air and moisture insensitivity are of high value and should attract attention from the synthetic community and find wide applications in organic synthesis. Finally, we successfully achieved a new three-component reaction of aldehyde, hydroxylamine hydrochloride, and alkenes for the synthesis of isoxazolines by exploiting the hypothetic mechanism with a green chemistry approach. This three-component oxidative cycloaddition is expected to have an extensive impact on application of cycloaddition of nitrile oxides in medicinal and organic synthesis.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.8b03829.

Experimental details, procedures, and characterization of all compounds (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: rtong@ust.hk. Fax: +(852) 23581594. Tel: +(852) 23587357

ORCID

Rongbiao Tong: 0000-0002-2740-5222

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This research was financially supported by the Research Grant Council of Hong Kong (GRF 605113, 16311716, 16303617) and the National Natural Science Foundation of China (NSFC 21472160 and 21772167).

■ REFERENCES

(1) Heaney, F. *Eur. J. Org. Chem.* **2012**, *2012*, 3043.
(2) Pellissier, H. *Tetrahedron* **2007**, *63*, 3235.
(3) (a) Gothelf, K. V.; Jørgensen, K. A. *Chem. Rev.* **1998**, *98*, 863. (b) Kissane, M.; Maguire, A. R. *Chem. Soc. Rev.* **2010**, *39*, 845.
(4) (a) Easton, C. J.; Hughes, C. M. M.; Savage, G. P.; Simpson, G. W. *Adv. Heterocycl. Chem.* **1994**, *60*, 261. (b) Roscales, S.; Plumet, J. *Org. Biomol. Chem.* **2018**, *16*, 8446.
(5) (a) Feuer, H., Ed. *Nitrile Oxides, Nitrones, and Nitroates in Organic Synthesis*; John Wiley & Sons, 2008. (b) Padwa, A., Pearson, W. H., Eds. *Synthetic Applications of 1,3-Dipolar Cycloaddition Chemistry toward Heterocycles and Natural Products*; John Wiley & Sons: New York, 2002.
(6) Tang, S.; He, J.; Sun, Y.; He, L.; She, X. *J. Org. Chem.* **2010**, *75*, 1961.
(7) Bonne, D.; Salat, L.; Dulcère, J.-P.; Rodriguez, J. *Org. Lett.* **2008**, *10*, 5409.
(8) Choe, H.; Cho, H.; Ko, H.-J.; Lee, J. *Org. Lett.* **2017**, *19*, 6004.
(9) Nomura, T.; Yokoshima, S.; Fukuyama, T. *Org. Lett.* **2018**, *20*, 119.
(10) (a) Bode, J. W.; Fraefel, N.; Muri, D.; Carreira, E. M. *Angew. Chem., Int. Ed.* **2001**, *40*, 2082. (b) Bode, J. W.; Carreira, E. M. *J. Am. Chem. Soc.* **2001**, *123*, 3611. (c) Fader, L. D.; Carreira, E. M. *Org. Lett.* **2004**, *6*, 2485. (d) Lohse-Fraefel, N.; Carreira, E. M. *Org. Lett.* **2005**, *7*, 2011. (e) Muri, D.; Lohse-Fraefel, N.; Carreira, E. M. *Angew. Chem., Int. Ed.* **2005**, *44*, 4036. (f) Becker, N.; Carreira, E. M. *Org. Lett.* **2007**, *9*, 3857. (g) Lohse-Fraefel, N.; Carreira, E. M. *Chem. - Eur. J.* **2009**, *15*, 12065.
(11) Maugein, N.; Wagner, A.; Mioskowski, C. *Tetrahedron Lett.* **1997**, *38*, 1547.
(12) Shimizu, T.; Hayashi, Y.; Furukawa, N.; Teramura, K. *Bull. Chem. Soc. Jpn.* **1991**, *64*, 318.
(13) Torssell, K. B. G.; Hazell, A. C.; Hazell, R. G. *Tetrahedron* **1985**, *41*, 5569.
(14) Shimizu, T.; Hayashi, Y.; Shibafuchi, H.; Teramura, K. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 2827.
(15) Mukaiyama, T.; Hoshino, T. *J. Am. Chem. Soc.* **1960**, *82*, 5339.
(16) McKillop, A.; Kobylecki, R. J. *Tetrahedron* **1974**, *30*, 1365.
(17) Zen, S.; Harada, K.; Nakamura, H.; Iitaka, Y. *Bull. Chem. Soc. Jpn.* **1988**, *61*, 2881.
(18) Nakamura, A.; Kanou, H.; Tanaka, J.; Imamiya, A.; Maegawa, T.; Miki, Y. *Org. Biomol. Chem.* **2018**, *16*, 541.
(19) Mendelsohn, B. A.; Lee, S.; Kim, S.; Teyssier, F.; Aulakh, V. S.; Ciufolini, M. A. *Org. Lett.* **2009**, *11*, 1539.
(20) Minakata, S.; Okumura, S.; Nagamachi, T.; Takeda, Y. *Org. Lett.* **2011**, *13*, 2966.
(21) Han, L.; Zhang, B.; Xiang, C.; Yan, J. *Synthesis* **2014**, *46*, 503.
(22) Read, M. W.; Ray, P. S. *J. Heterocycl. Chem.* **1995**, *32*, 1595.
(23) Tanaka, S.; Kohmoto, S.; Yamamoto, M.; Yamada, K. *Nippon Kagaku Kaishi* **1992**, *1992*, 420.

DOI: 10.1021/acs.orglett.8b03829
Org. Lett. XXXX, XXX, XXX−XXX

(24) Gi, H.-J.; Xiang, Y.; Schinazi, R. F.; Zhao, K. *J. Org. Chem.* **1997**, *62*, 88.
(25) Armstrong, S. K.; Collington, E. W.; Knight, J. G.; Naylorb, A.; Warren, S. *J. Chem. Soc., Perkin Trans. 1* **1993**, *1*, 1433.
(26) Kizer, D. E.; Miller, R. B.; Kurth, M. J. *Tetrahedron Lett.* **1999**, *40*, 3535.
(27) Moriya, O.; Nakamura, H.; Kageyama, T.; Urata, Y. *Tetrahedron Lett.* **1989**, *30*, 3987.
(28) Kiegiel, J.; Popławska, M.; Jóźwik, J.; Kosior, M.; Jurczak, J. *Tetrahedron Lett.* **1999**, *40*, 5605.
(29) Bhosale, S.; Kurhade, S.; Prasad, U. V.; Palle, V. P.; Bhuniya, D. *Tetrahedron Lett.* **2009**, *50*, 3948.
(30) Pandit, P.; Chatterjee, N.; Halder, S.; Hota, S. K.; Patra, A.; Maiti, D. K. *J. Org. Chem.* **2009**, *74*, 2581.
(31) Radhakrishna, A. S.; Sivaprakash, K.; Singh, B. B. *Synth. Commun.* **1991**, *21*, 1625.
(32) Yoshimura, A.; Middleton, K. R.; Todora, A. D.; Kastern, B. J.; Koski, S. R.; Maskaev, A. V.; Zhdankin, V. V. *Org. Lett.* **2013**, *15*, 4010.
(33) Yoshimura, A.; Zhu, C.; Middleton, K. R.; Todora, A. D.; Kastern, B. J.; Maskaev, A. V.; Zhdankin, V. V. *Chem. Commun.* **2013**, *49*, 4800.
(34) Li, Z.; Tong, R. *J. Org. Chem.* **2016**, *81*, 4847.
(35) Xu, J.; Tong, R. *Green Chem.* **2017**, *19*, 2952.
(36) Zhao, G.; Tong, R. *Green Chem.* **2019**, DOI: 10.1039/C8GC03030H.
(37) Ren, J.; Tong, R. *Org. Biomol. Chem.* **2013**, *11*, 4312.
(38) Bianchi, G.; De Micheli, C.; Gandolfi, R.; Grünanger, P.; Finzi, P. V.; de Pava, O. V. *J. Chem. Soc., Perkin Trans. 1* **1973**, *1*, 1148.
(39) Copéret, C.; Adolfsson, H.; Khuong, T.-A. V.; Yudin, A. K.; Sharpless, K. B. *J. Org. Chem.* **1998**, *63*, 1740.
(40) Youssif, S. *ARKIVOC* **2001**, *1*, 242.
(41) McIntosh, M. L.; Naffziger, M. R.; Ashburn, B. O.; Zakharov, L. N.; Carter, R. G. *Org. Biomol. Chem.* **2012**, *10*, 9204.
(42) Barybin, M. V.; Diaconescu, P. L.; Cummins, C. C. *Inorg. Chem.* **2001**, *40*, 2892.
(43) (a) Huisgen, R. *Angew. Chem., Int. Ed. Engl.* **1963**, *2*, 633. (b) Firestone, R. A. *J. Org. Chem.* **1968**, *33*, 2285. (c) Huisgen, R. *J. Org. Chem.* **1976**, *41*, 403. (d) Di Valentin, C.; Freccero, M.; Gandolfi, R.; Rastelli, A. *J. Org. Chem.* **2000**, *65*, 6112.

DOI: 10.1021/acs.orglett.8b03829
Org. Lett. XXXX, XXX, XXX−XXX