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Communication

Mn(III)-mediated radical cascade reaction of boronic acids with isocyanides: synthesis of diimide derivatives

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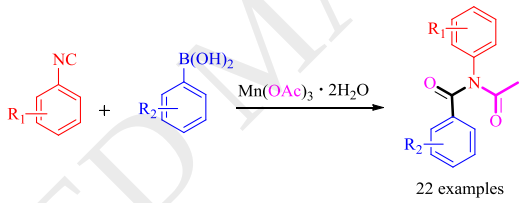
Graphical Abstract



A manganese(III)-promoted oxidative radical cascade reaction of easily accessible arylboronic acids with isocyanides to construct diimide derivatives was studied. This protocol provides a new way to synthesis of acetyl diimide derivatives. New C-C, C-N and C=O bonds were formed in one step.

ABSTRACT

A manganese(III)-promoted oxidative radical cascade reaction of easily accessible arylboronic acids with isocyanides to construct diimide derivatives was studied. This protocol provides a new way to synthesis of acetyl diimide derivatives. New C-C, C-N and C=O bonds were formed in one step.

Keywords:
$Mn(OAc)_3$
Isocyanide
Arylboronic Acid
Diimide Derivatives
Radical cascade

In nature, there are a wide range of compounds containing amide structures, which are important intermediates and structural units in

organic synthesis [1]. In addition to amides, diimide structures are also important organic moieties in fine chemicals. For example, TAED, Dermagan, Formothion, Thalidomide, Pecilocin, *etc.* have properties such as insecticidal, anti-tumor, anti-fungal, and anti-anxiety drugs (Fig. 1) [2]. Therefore, it is of great significance to prepare chemical compounds with diimide structure. The traditional method for preparing diimides is achieved by nucleophilic substitution of an amide with an activated carboxylic acidderivative (such as an acid chloride or anhydride) in the presence of a base [3]. In addition, selective oxidation by amides is also known [4]. In recent years, the interest of researchers has been drawn to the use of carbon monoxide (CO) as the cheap C1 synthon to synthesize carbonyl-containing chemicals [5]. Recently, Prof. Wu's, Beller's, and Lei's group have reported the efficient use of CO for the synthesis of compounds containing imide structures (Scheme 1, eqs. 1 and 2) [6].

Isonitriles are also important C1 synthons and play an important role in the synthesis of nitrogen-containing heterocyclic compounds [7,8]. Free-radical reactions involving isonitriles are an important part of isonitrile chemistry. In recent years, the transition metal-catalyzed radical reactions involving isonitriles have been tremendously developed [9]. Our group has reported the transition metal-catalyzed diaryl isonitriles involved in free radical reactions to prepare phenanthridine derivatives [10]. Here, we first report the successful preparation of diimide derivatives by reaction of phenylboronic acid with isonitrile under the catalysis of $Mn(OAc)_3$ (Scheme 1, eq. 3).

Initially, we attempted the reaction of 1-isocyano-4-methoxybenzene (**1a**), phenylboronic acid (**2a**), 3 equivalents of $Mn(OAc)_3{\cdot}2H_2O$ as oxidant in MeCN at 65 °C for 12 h, Gratifyingly, target product **3a** could be obtained with 22% LC yield (Table 1, entry 1). The reaction failed to afford **3a** when other oxidant, such as $Cu(OAc)_2$ and AgOAc were used (Table 1, entries 2-3). Then, we studied the effects of the solvent and found that 1,4-dioxane, DMF, DCE, and DME did not give better results (Table 1, entries 4-7). Next we screened the reaction temperature and found that the reaction was best at 100 °C, and the target product could be obtained with a 53% LC yield (Table 1, entries 8-10). Finally, we optimized the reaction time and found that the reaction yield was highest for 4 h (Table 1, entries 11-14). When we used a catalytic amount of $Mn(OAc)_3{\cdot}2H_2O$ and $Mn(acac)_3$, 1.5 equiv. of NaOAc, the reaction failed to afford **3a** (Table 1, entries 15-16).

With the optimized conditions in hand, we began to study the scope of various aryl isonitriles (Scheme 2). It was found that when we used 2,6-dimethyl aryl isocyanide, 2,4,6-trimethyl aryl isocyanide and 2,6-diethyl aryl isonitrile to react with phenylboronic acid, the target products (**3b, 3c, 3d**) could be obtained in 49% to 71% yields. The reaction of **2a** with 1-isocyano-4-methylbenzene **1e** furnished the desired product **3e** in 40% yield. The reaction of *p*-methoxyphenyl isonitrile with *p*-methoxyphenylboronic acid could result in the desired product **3f** in 56% yield. Then we used 2,4,6-trimethylphenylisonitrile to react with *p*-acetylphenylboronic acid, the desired product **3g** was obtained in 55% yield. However, when we select the halogen-substituted and 3-nitro-substituted isonitriles to react with different substituted phenylboronic acids, The corresponding imide product was not obtained, but only the corresponding amide product (**3h, 3i**) was obtained. Besides, the reaction of *tert*-butylisonitrile with **2a** also lead to the corresponding amide compounds **3j** in 46% yield (detail information of **3a–j** see Supporting information).

Thereafter, we investigated a range of different phenylboronic acids **2** (Scheme 3). When *p*-methylphenylboronic acid reacted with *m*-methylphenylboronic acid, the target product (**4a, 4b**) could be obtained in 65% and 69% yields, respectively. The reaction of *p*-methoxyphenylboronic acid and **1b** afforded the desired product **4c** in 49% yield. Then, when we selected halogen-substituted phenylboronic acid at different positions, the target product (**4d~4g**) could be obtained in 53%~64% yields. Electron-withdrawing groups, such as CN substituted phenylboronic acid (**4h**) could also lead to the desired products **4b** in 40% yield. When [1,1'-biphenyl]-4-ylboronic acid was subjected to the reaction with **1b**, **4i** could be obtained in 52% yield. The reaction of 2-naphthaleneboronic acid with **1b** furnished the desired product (**4j**) in 64% yield. Unfortunately, the reactions of heterocycle-functionalized boric acid **2k** and alkylboronic acid **2l** failed to give the desired products **4k** and **4l** (detail information of **4a–j** see Supporting information).

To gain insights into the mechanism of this reaction, two control experiments were conducted (Scheme 4). When 2 equiv. of TEMPO (2,2,6,6-tetramethylpiperidine-1-oxyl) was added to the reaction system of **1b** with **2a**, As expected, the desired product *N*-acetyl-*N*-(2,6-dimethylphenyl)benzamide (**3b**) was not detected, and the reaction system was very messy. This result indicated that the reaction may have experienced a free radical process. When 2 equiv. of another radical scavenger (1,1-diphenylethylene) was added to the reaction system of **1b** with **2a**, We successfully obtained the captured imine radical (II) product **3b'** in an isolated yield of 41% (detail information of **3b'** see Supporting information). It was proved that the reaction went through an imine free radical intermediate.

Based on the literature reports [11] and the above experimental results, we proposed a plausible reaction mechanism in Scheme 5. First, the phenylboronic acid compound produce phenyl radical **I** under the action of Mn(III), then phenyl radical **I** reacts with **1a** to give the imine radical intermediate **II**. Next, **II** gives the nitrogen positive ion intermediate **III** under the oxidation of Mn(III). **III** is attacked by acetate ions to obtain intermediate **IV**, which is then rearranged intramolecularly to give the target product diimide **3a**.

In summary, we have reported a manganese(III)-catalyzed oxidative radical cascade reaction of isonitrile and phenylboronic acid under mild conditions. A new C-C bond, C-N bond, and C=O bond were constructed in one step, and a series of diimide derivatives was successfully constructed. It provided a practical method for the preparation of diimide derivatives, which has the advantages of easy availability of starting materials, simple operation.

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References

[1] (a) M. Hutchby, Novel Synthetic Chemistry of Ureas and Amides, Springer, New York, 2013.
(b) D.Q. Dong, S.H. Hao, H. Zhang, Z.L. Wang, Chin. Chem. Lett. 28 (2017) 1597-1599.
[2] (a) J. Zhang, S.H. Hong, Org. Lett. 14 (2012) 4646–4649.
(b) W.D. Figg, S. Raje, K.S. Bauer, et al., J. Pharm. Sci. 88 (1999) 121-125.
(c) S. Markonkawkeyoon, R.N.R. Limson, A.L. Moreira, V. Schauf, G. Kaplan. Proc. Natl. Acad. Sci. U. S. A. 90 (1993) 5974-5978.
(d) R. Cumin, E.F. Bandle, E. Gamzu, W.E. Haefely. Psychopharmacology 78 (1982) 104–111.
(e) J. Kang, V.K.R. Tangadanchu, L. Gopala, et al., Chin. Chem. Lett. 28 (2017) 1369-1374.
[3] (a) N.A. Al-Awadi. J. Chem. Soc. Perkin Trans 2 (1990) 2187-2189.
(b) P.Y. Reddy, S. Kondo, T. Toru, Y. Ueno. J. Org. Chem. 62 (1997) 2652–2654.
[4] (a) K.C. Nicolaou, C.J.N. Mathison, Angew. Chem. Int. Ed. 44 (2005) 5992-5997;
(b) W.H. Huang, M.L. Wang, H. Yue, Synthesis 9 (2008) 1342-1344.
(c) X. Ye, C.S. Xie, Y.Y. Pan, L.H. Han, T. Xie, Org. Lett. 12 (2010) 4240–4243.
(d) V.K. Robert, S.G. Ning, R.S. Ronald, J.W. Lawrence. J. Am. Chem. Soc. 128 (2006) 5695-5702.
(e) T. Kaicharla, M. Thangaraj, A.T. Biju, Org. Lett. 16 (2014) 1728–1731.
(f) J. Kim, S.H. Hong., Org. Lett. 16 (2014) 4404-4407.
(g) T.B. Nguyen, J. Sorres, M.Q. Tran, L. Ermolenko, A. Al-Mourabit, Org. Lett. 14 (2012) 3202-3205.
[5] (a) X.F. Wu, H. Neumann, M. Beller, Chem. Rev. 113 (2013) 1-35.
(b) X.F. Wu, H. Neumann, ChemCatChem 4 (2012) 447-458.
(c) Q. Liu, H. Zhang, A.W. Lei, Angew. Chem. Int. Ed. 50 (2011) 10788-10799;
(d) X.F. Wu, H. Neumann, M. Beller, ChemSusChem 6 (2013) 229-241.
(e) C.H. Schiesser, U. Wille, H. Matsubara, I. Ryu, Acc. Chem. Res. 40 (2007) 303-313.
(f) S. Sumino, A. Fusano, T. Fukuyama, I. Ryu, Acc. Chem. Res. 47 (2014) 1563–1574.
(g) I. Ryu, N. Sonoda, Angew. Chem. Int. Ed. 35 (1996) 1050-1066;
(h) I. Ryu, Chem. Rec. 2 (2002) 249-258.
[6] (a) H.Q. Li, K.W. Dong, H. Neumann, M. Beller, Angew. Chem. Int. Ed. 54 (2015) 10239-10243.
(b) Y.H. Li, K.W. Dong, F.X. Zhu, Z.C. Wang, X.F. Wu, Angew. Chem. Int. Ed. 55 (2016) 7227-7230.
(c) L.J. Lu, D.Y. Cheng, Y.F. Zhan, et al., Chem. Commun. 53 (2017) 6852-6855.
[7] (a) J. Li, Y. He, S. Luo, et al., J. Org. Chem. 80 (2015) 2223-2230.
(b) Y.Y. Pan, Y.N. Wu, Z.Z. Chen, et al., J. Org. Chem. 80 (2015) 5764–5770.
(c) Q. Yang, C. Li, M.X. Cheng, S.D.Yang, ACS Catal. 6 (2016) 4715–4719.
(d) Z.B. Chen, Y. Zhang, Q. Yuan, et al., J. Org. Chem. 81 (2016) 1610-1616.
(e) Q. Zheng, Q. Ding, C. Wang, W. Chen, Y. Peng, Tetrahedron 72 (2016) 952-958.
(f) J. Peng, Y. Gao, W. Hu, et al., Org. Lett. 18 (2016) 5924–5927.
(g) G. Qiu, Q. Wang, J. Zhu, Org. Lett. 19 (2017) 270–273.
(h) X. Huang, S. Xu, Q. Tan, et al., Chem. Commun. 50 (2014) 1465-1468.
(i) S. Kim, S.H. Hong, Adv. Synth. Catal. 357 (2015) 1004-1012.
(j) K. Takamatsu, K. Hirano, M. Miura, Org. Lett. 17 (2015) 4066–4069.
(k) J. Lei, X. Wu, Q. Zhu, Org. Lett. 17 (2015) 2322–2325.
(l) D. Li, T. Mao, J. Huang, Q. Zhu, Chem. Commun. 53 (2017) 1305-1308.
(m) J. Liu, Z. Liu, P. Liao, et al., Angew. Chem., Int. Ed. 54 (2015) 10618-10622.
(n) H. Wang, R.K. Kumar, Y. Yu, et al., Chem. Asian J. 11 (2016) 2841-2845.
(o) Z. Hu, J. Dong, Y. Men, et al., Angew. Chem. Int. Ed. 56 (2017) 1805-1809.
(p) K. Sugano, T. Tanase, K. Kobayashi, Y. Yamamoto, Chem. Lett. (1991) 921-924.
(q) Q. Gao, P. Zhou, F. Liu, et al., Chem. Commun. 51 (2015) 9519-9522.
[8] (a) Z.Y. Gu, T.H. Zhu, J.J. Cao, et al., ACS Catal. 4 (2014) 49-52.
(b) T.H. Zhu, S.Y. Wang, G.N. Wang, S.J. Ji, Chem. Eur. J. 19 (2013) 5850-5853
(c) T.H. Zhu, X.P. Xu, J.J. Cao, et al., Adv. Synth. Catal. 356 (2014) 509-518.
(d) T.H. Zhu, S.Y. Wang, T.Q. Wei, S.J. Ji, Adv. Synth. Catal. 357 (2015) 823-828.
(e) T.H. Zhu, S.Y. Wang, Y.Q. Tao, T.Q. Wei, S.J. Ji, Org. Lett. 16 (2014) 1260–1263.
(f) P. Xu, T.H. Zhu, T.Q. Wei, S.Y. Wang, S.J. Ji, RSC Adv. 6 (2016) 32467-32470.
(g) P. Xu, F. Wang, T.Q. Wei, et al., Org. Lett. 19 (2017) 4484–4487.
(h) Y. Fang, Z.L. Zhu, P. Xu, S.Y. Wang, S.J. Ji, Green Chem. 19 (2017) 1613-1618.
[9] (a) D.P. Curran, H. Liu, J. Am. Chem. Soc. 113 (1991) 2127–2132.
(b) D.P. Curran, H. Liu, J. Am. Chem. Soc. 114 (1992) 5863–5864.
(c) H. Josien, D. Bom, D.P. Curran, Y.H. Zheng, T.C. Chou, Bioorg. Med. Chem. Lett. 7 (1997) 3189-3194.
(d) H. Josien, S.B. Ko, D. Bom, D.P. Curran, Chem. Eur. J. 4 (1998) 67-83.
(e) B. Janza, A. Studer, Org. Lett. 8 (2006) 1875–1878.
(f) T. Mitamura, K. Iwata, A. Ogawa, Org. Lett. 11 (2009) 3422–3424.
(g) T. Mitamura, A. Ogawa, J. Org. Chem. 76 (2011) 1163–1166.
(h) B. Zhang, A. Studer, Org. Lett. 16 (2014) 1216–1219.
[10] (a) J.J. Cao, T.H. Zhu, Z.Y. Gu, et al., Tetrahedron 70 (2014) 6985-6990.
(b) J.J. Cao, X. Wang, S.Y. Wang, S.J. Ji, Chem. Commun. 50 (2014) 12892-12895.
[11] (a) A.S. Demir, O. Reis, M. Emrullahoglu, J. Org. Chem. 68 (2003) 578–580.
(b) H. Wang, Y. Yu, X.H. Hong, B. Xu, Chem. Commun. 50 (2014) 13485-13488.
(c) X.M. Huang, S.G. Xu, Q.T. Tan, et al., Chem. Commun. 50 (2014) 1465-1468.
(d) G.B. Yan, M.H. Yang, X.M. Wu, Org. Biomol. Chem. 11 (2013) 7999-8008.
[12] (a) Y. Wang, M. Li, J. Peng, C. Chen, Angew. Chem. Int. Ed. 52 (2013) 5323-5327.
(b) X. Su, M. Li, Y. Wang, et al., Chem. Commun. 49 (2013) 6752-6754.
(c) C.K. Cao, J.Y. Sheng, C. Chen. Synthesis 49 (2017) 5081-5092.
(d) Y. Wang, X. Su, C. Chen. Synlett 24 (2013) 2619-2623.

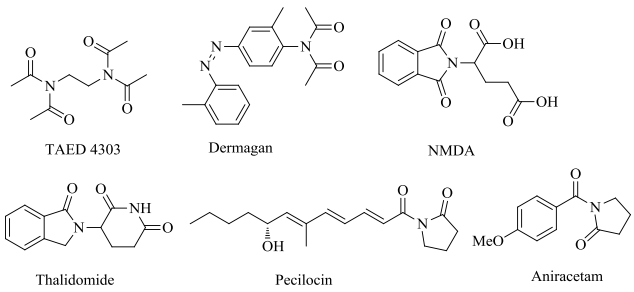
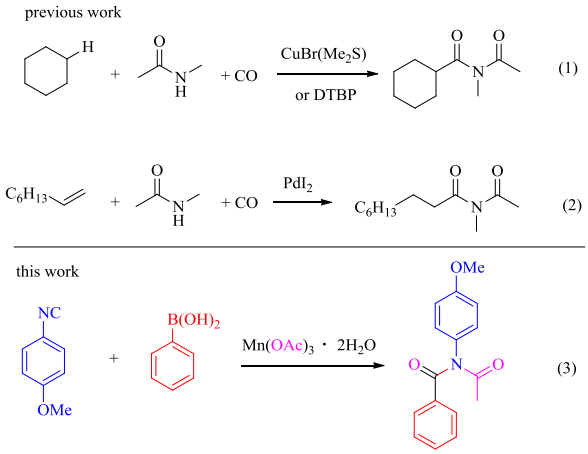
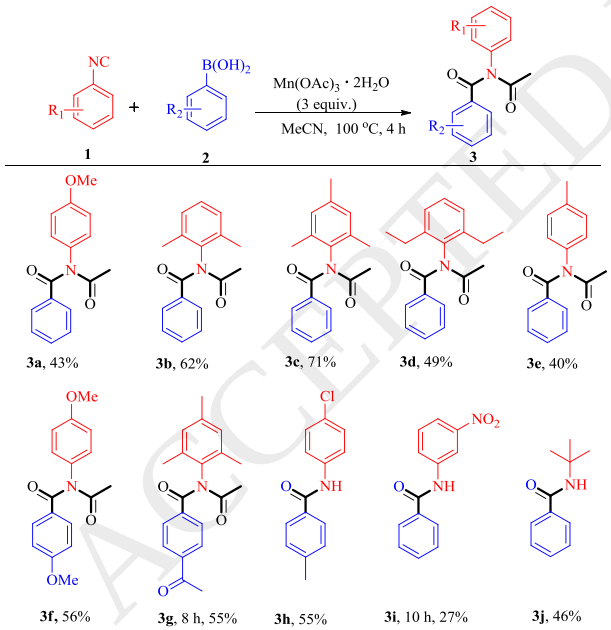


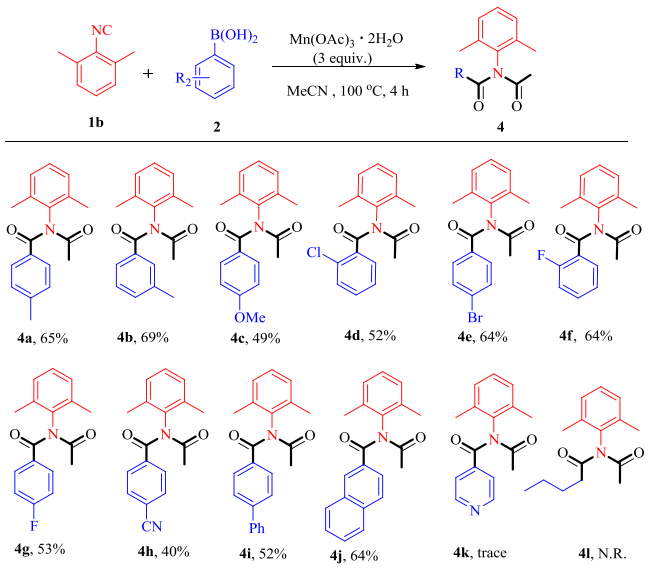
Fig. 1. Examples of imide-containing bioactive molecules.



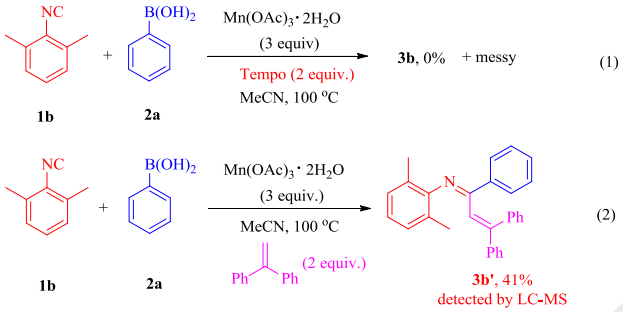
Scheme 1. Synthesis of imide using CO along with this work.



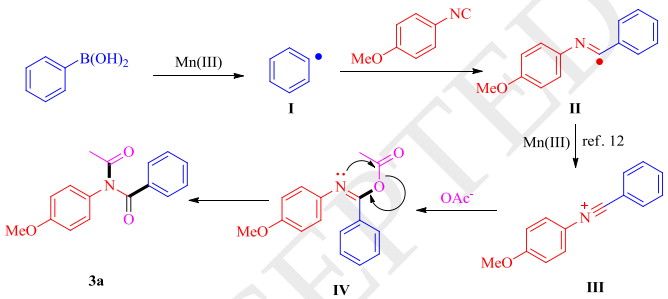
Scheme 2. Scope study of isonitriles. Reaction conditions: **1** (0.2 mmol), **2** (0.24 mmol), $Mn(OAc)_3{\cdot}2H_2O$ (3.0 equiv.), MeCN (2 mL), under air. Isolated yield



Scheme 3. Scope study of phenylboronic acids. Reaction conditions: **1** (0.2 mmol), **2** (0.24 mmol), $Mn(OAc)_3{\cdot}2H_2O$ (3.0 equiv.), MeCN (2 mL), under air. Isolated yield.

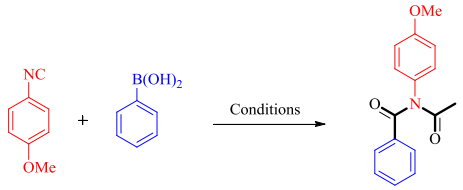


Scheme 4. Control experiments.



Scheme 5. A plausible mechanism.

Table 1 Optimization of the reaction conditions.[a]



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

Entry	Oxidant	Solvent	Temp. (°C)	Time (h)	LC yield (%)[b]
1	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	65	12	22
2	$Cu(OAc)_2$	MeCN	65	12	trace
3	AgOAc	MeCN	65	12	trace
4	$Mn(OAc)_3{\cdot}2H_2O$	Dioxane	65	12	trace
5	$Mn(OAc)_3{\cdot}2H_2O$	DMF	65	12	N.R
6	$Mn(OAc)_3{\cdot}2H_2O$	DCE	65	12	trace
7	$Mn(OAc)_3{\cdot}2H_2O$	DME	65	12	trace
8	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	80	12	32
9	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	12	53
10	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	110	12	42
11	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	2	42
12	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	4	58(43[c])
13	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	5	53
14	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	6	42
15[d]	$Mn(OAc)_3{\cdot}2H_2O$	MeCN	100	4	N.R
16[d]	$Mn(acac)_3$	MeCN	100	4	N.R

[a] Reaction conditions: **1a** (0.2 mmol), **2a** (0.24 mmol), oxidant (3.0 equiv.), solvent (2 mL), under air.
[b] The yields were determined by LC analysis using biphenyl as the internal standard.
[c] Isolated yield.
[d] Oxidant (0.1 equiv.), 1.5 equiv. of NaOAc was added.