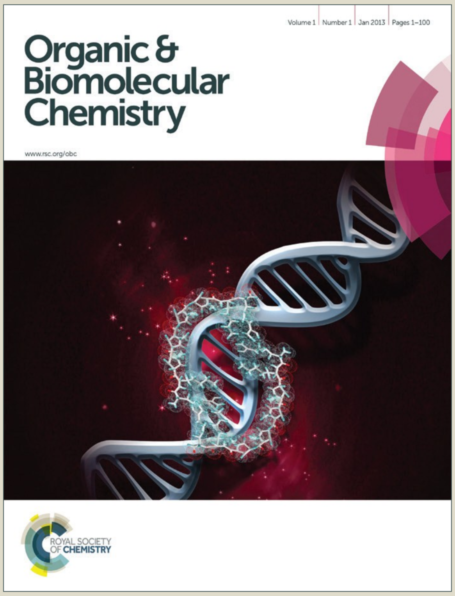
View Article Online
View Journal

Organic & Biomolecular Chemistry

This article can be cited before page numbers have been issued, to do this please use: L. Hua, H. Li, F. Qing, Y. Huang and X. Xu, *Org. Biomol. Chem.*, 2016, DOI: 10.1039/C6OB01567K.



ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/obc

View Article Online
DOI: 10.1039/C6OB01567K

Journal Name

COMMUNICATION

Iodine-mediated regioselective synthesis of vinyl triflones from styrenes with CF_3SO_2Na

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

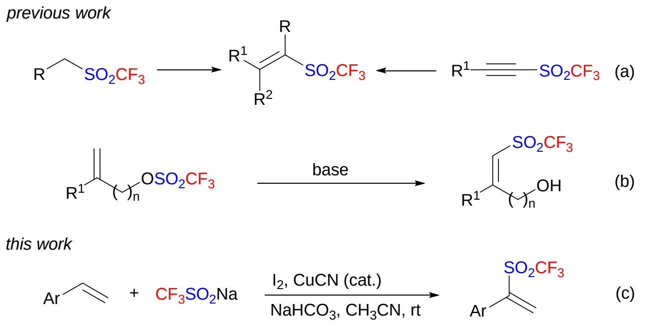
www.rsc.org/

Li-Na Hua,[a] Huan Li,[a] Feng-Ling Qing,[a,b] Yangen Huang*[a] and Xiu-Hua Xu*[a,b]

An unexpected regioselective synthesis of vinyl triflones was developed. This iodine-mediated C—H triflylation of styrenes with CF_3SO_2Na occurred at room temperature affording various vinyl triflones, which could be used for the preparation of other CF_3SO_2-containing compounds.

The wide application of fluorinated compounds in pharmaceuticals, agrochemicals, and materials[1] have resulted in increasing interest in fluorine-containing groups and fluorinating methods.[2] Among various fluorine-containing groups, the trifluoromethanesulfonyl (triflyl, SO_2CF_3, Tf) group is the strongest electron-withdrawing group with high lipophilicity.[3] The CF_3SO_2-containing compounds are frequently used as structural units in bioactive compounds,[4] catalysts or ligands,[5] and advanced functional materials.[6] In this context, substantial efforts have been devoted to the development of new synthetic methods of CF_3SO_2-containing compounds,[2f] especially for aryl trifluoromethanesulfones (triflones).[7] In contrast, much less attention has been paid in the preparation of vinyl triflones, despite these compounds are attractive in organic synthesis and pharmaceutical industry. Normally, vinyl triflones are prepared by transformation from alkyl triflones[8] or alkynyl triflones (Scheme 1a).[9] The intramolecular triflyl rearrangement, reported by the groups of Okauchi, Maas, and ours,[10] provides an alternative approach to vinyl triflones (Scheme 1b). However, the direct incorporation of triflyl into alkenes has never been reported.

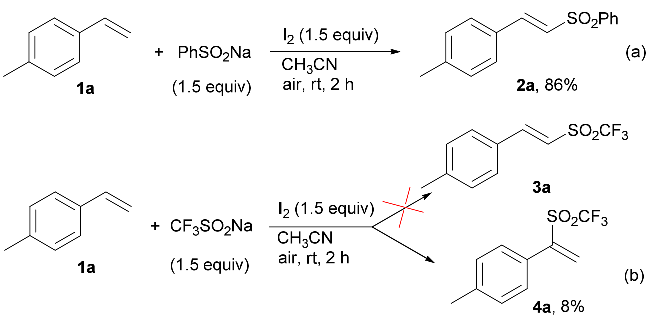
Pd- or Cu-catalyzed cross-coupling reactions of vinyl halides, vinyl boronic acids, or alkynes with sulfinate salts provides a routine and direct approach to vinyl sulfones.[11] However, the use of CF_3SO_2Na as a nucleophilic coupling partner remains to be a challenge, because the strong electron-withdrawing character of the triflyl group[3] reduces its nucleophilicity.[12]



Scheme 1. Methods for the preparation of vinyl triflones

Recently, a variety of transition-metal-free protocols,[13,14] especially iodine-catalyzed/mediated direct sulfonylation of alkene and alkyne derivatives[14] have been developed for the efficient synthesis of vinyl sulfones. Inspired by these achievements, we were dedicated to exploring the direct triflylation of alkenes under transition-metal-free conditions. Herein, we report our progress in the iodide-mediated regioselective synthesis of vinyl triflones from styrenes with CF_3SO_2Na (Scheme 1c). To the best of our knowledge, this work represents the first example of direct C—H triflylation of alkenes.

We embarked on our studies with the repetition of the iodine-mediated synthesis of vinyl sulfones[14e] by the reaction of 1-methyl-4-vinylbenzene **1a** and $PhSO_2Na$ (Scheme 2a).



Scheme 2. I_2-mediated synthesis of vinyl sulfones

---

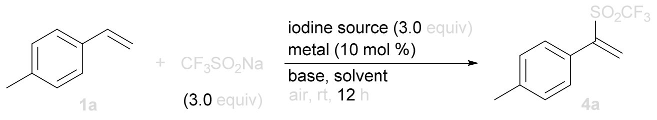
[a] College of Chemistry, Chemical Engineering and Biotechnology, Donghua University, 2999 North Renmin Lu, Shanghai 201620, China.
[b] Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Science, 345 Lingling Lu, Shanghai 200032, China.
E-Mail: hyg@dhu.edu.cn or xuxiuhua@sioc.ac.cn

† Electronic Supplementary Information (ESI) available: See DOI: 10.1039/

After obtaining vinyl sulfone **2a** in 86% yield, we then decided to switch $PhSO_2Na$ to CF_3SO_2Na for the analogous synthesis of vinyl triflones (Scheme 2b). In contrast to the high yield of vinyl sulfone **2a**, the conversion of **1a** to vinyl triflone was low. Noteworthily, a novel unknown vinyl triflone **4a**, not the expected product **3a**,[15] was obtained.

The above interesting result encouraged us to optimize the reaction conditions for improving the yield of vinyl triflone **4a** (Table 1). First, a variety of iodine sources were screened. It was found that molecular iodine was the most effective (entry 1). NIS or $PhI(OAc)_2$/KI gave lower yields, while ICl could not promote this reaction (entries 2-4). Considering the fact that HI would be generated from the reaction system, the addition of a base should benefit this reaction. Indeed, higher yield of **4a** was observed in the presence of an organic or inorganic base (entries 5-8). The reaction performed with two equivalents of $NaHCO_3$ gave the best result (entry 8). Subsequently, the effect of catalytic metal salt was evaluated (entries 9-12). Among the common metal salts, CuI could result in slightly higher yield (entry 9). Other metal salts, such as $FeCl_2$, were ineffective. Further screening of copper salts revealed CuCN was optimal, giving **4a** in 57% yield (entry 12). Finally, different solvents including DCE, THF, DMF, and DMSO were investigated (entries 13-16). However, none of them gave better result than that of CH_3CN. It was noteworthy that lowering or elevating reaction temperature also resulted in lower yields (entries 17 and 18).

Table 1. Optimization of reaction conditions[a]

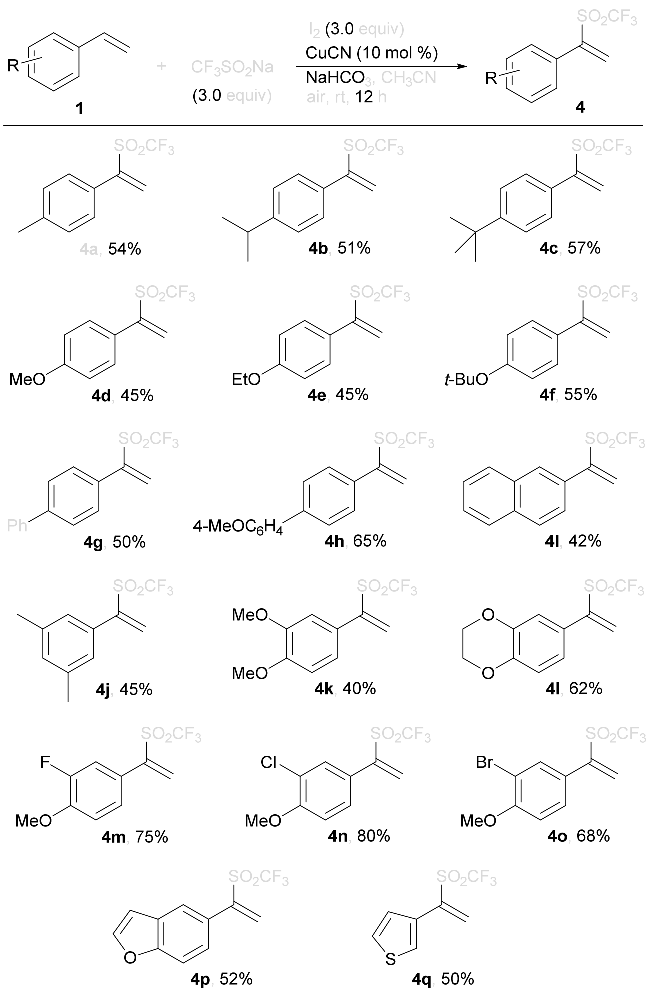


entry	iodine source	Base	metal	solvent	yield[b] (%)
1	I_2	—	—	CH_3CN	18
2	NIS	—	—	CH_3CN	14
3	$PhI(OAc)_2$/KI	—	—	CH_3CN	11
4	ICl	—	—	CH_3CN	0
5	I_2	DBU	—	CH_3CN	20
6	I_2	NaOAc	—	CH_3CN	22
7	I_2	K_2CO_3	—	CH_3CN	37
8	I_2	$NaHCO_3$	—	CH_3CN	40
9	I_2	$NaHCO_3$	CuI	CH_3CN	45
10	I_2	$NaHCO_3$	$FeCl_2$	CH_3CN	33
11	I_2	$NaHCO_3$	CuTc	CH_3CN	38
12	I_2	$NaHCO_3$	CuCN	CH_3CN	57
13	I_2	$NaHCO_3$	CuCN	DCE	trace
14	I_2	$NaHCO_3$	CuCN	THF	7
15	I_2	$NaHCO_3$	CuCN	DMF	16
16	I_2	$NaHCO_3$	CuCN	DMSO	28
17[c]	I_2	$NaHCO_3$	CuCN	CH_3CN	41
18[d]	I_2	$NaHCO_3$	CuCN	CH_3CN	28

[a]Reaction conditions: **1a** (0.2 mmol), CF_3SO_2Na (0.6 mmol), iodine source (0.6 mmol), base (0.4 mmol), metal salt (0.02 mmol), solvent (1.0 mL), under air, rt, 12 h. [b]Yields determined by ^{19}F NMR spectroscopy using trifluoromethoxybenzene as an internal standard. [c]50 °C. [d]0 °C.

Scheme 3. Iodine-mediated regioselective synthesis of vinyl triflones[a]

View Article Online
DOI: 10.1039/C6OB01567K

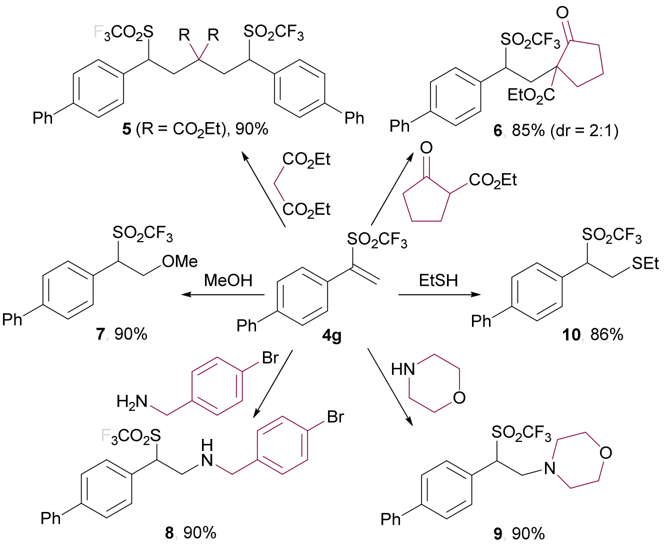


[a]Reaction conditions: **1** (0.5 mmol), CF_3SO_2Na (1.5 mmol), I_2 (1.5 mmol), $NaHCO_3$ (1.0 mmol), CuCN (0.05 mmol), CH_3CN (2.0 mL), under air, rt, 12 h, isolated yields.

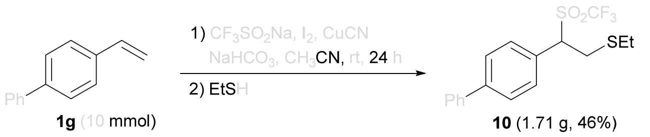
With the optimized reaction conditions in hand, the substrate scope of this protocol was then examined. As shown in Scheme 3, a range of styrenes (**1a**-**1o**) participated in the reaction giving vinyl triflones **4a**-**4o** in moderate yields along with the recovery of the starting materials in low yields. In general, the electron-donating substituent such as alkyl, alkoxyl, or aryl group was essential for this transformation. The aromatic fluoride (**1m**), chloride (**1n**), and bromide (**1o**) were tolerated under the standard reaction conditions, thus providing opportunities for additional transformations. In the cases of styrenes bearing strong electron-withdrawing substituents including ester, nitro, and cyano, low conversion was obtained. Unfortunately, neither the sterically hindered *ortho*-substituted styrenes nor the unactivated alkenes were suitable substrates. It was noteworthy that benzofuran- or thiophene-derived styrenes (**1p**, **1q**) were applicable to the reaction, affording the vinyl triflones **4p** and **4q** in moderate yields. The structure of product **4h** was further confirmed by HMQC and DEPT135 NMR spectra (see ESI).

View Article Online
DOI: 10.1039/C6OB01567K

Scheme 4. Transformation of compound **4g**

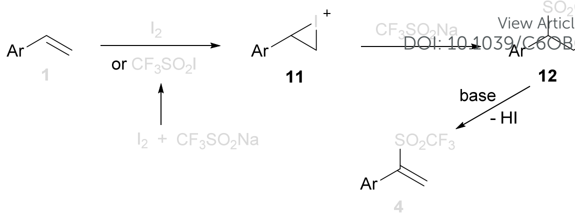


Scheme 5. Gram-scale preparation of **10** from **1g**



The hitherto unknown vinyl triflones **4** are compounds with great potential for further synthetic manipulation, notably as the excellent Michael addition acceptors. For instance, the reaction of vinyl triflone **4g** with different *C*-, *O*-, *N*-, and *S*-nucleophiles afforded the addition products **5**-**10** in good yields, respectively (Scheme 4). These compounds are formal difunctionalized products from styrene **1g** with the simultaneous introduction of one triflyl group and the other functional group. In fact, the gram-scale preparation of **10** could be performed directly from styrene **1g** (10 mmol) without the purification of intermediate **4g** (Scheme 5).

To gain insight into the reaction mechanism, the radical trap experiments were performed by adding 2,2,6,6-tetramethylpiperidinyloxy (TEMPO) or 2,6-di-*tert*-butyl-4-methylphenol (BHT) to the reaction mixture. Surprisingly, only trace of the desired product was detected in the presence of TEMPO, whereas BHT had no obvious effect on the reaction yield. We surmised that the detrimental effect of TEMPO might arise from its oxidation ability.[16] Though we could not firmly preclude the radical pathway, we were more inclined towards a cationic reaction mechanism accordingly to our experimental results and other related works.[17] As shown in Scheme 6, the electrophilic addition of iodine or CF_3SO_2I, in situ generated from the reaction of CF_3SO_2Na and I_2, onto styrenes **1** gave a three-membered cyclic iodonium ion intermediate **11**. Subsequent nucleophilic attack on **11** by CF_3SO_2Na in a Markovnikov fashion afforded iodotriflylated product **12**. At last, spontaneous elimination of HI took place yielding vinyl triflones **4**.[14a,b,e,g-i] However, the exact role of CuCN in this reaction remains unclear.



Scheme 6. Proposed reaction mechanism

In conclusion, we have developed an iodine-mediated direct C—H triflylation of styrenes with CF_3SO_2Na. This reaction offers a new route for the regioselective synthesis of vinyl triflones, which can undergo Michael addition by different nucleophiles to afford a series of CF_3SO_2-containing compounds. Further investigations of the mechanism and the application of this method are ongoing in our laboratory.

We are grateful for the financial support from National Natural Science Foundation of China (21502215, 21421002, 21332010, 21272036), National Basic Research Program of China (2012CB21600), Strategic Priority Research Program of the Chinese Academy of Sciences (XDB20020000), Youth Innovation Promotion Association CAS (No. 2016234), and Shanghai Pujiang Program (No. 15PJ1410300).

Notes and references

1 (a) K. Müller, C. Faeh and F. Diederich, *Science*, 2007, **317**, 1881; (b) S. Purser, P. R. Moore, S. Swallow and V. Gouverneur, *Chem. Soc. Rev.*, 2008, **37**, 320; (c) N. A. Meanwell, *J. Med. Chem.*, 2011, **54**, 2529; (d) M. Cametti, B. Crousse, P. Metrangolo, R. Milani and G. Resnati, *Chem. Soc. Rev.*, 2012, **41**, 31; (e) J. Wang, M. Sánchez-Roselló, J. L. Aceña, C. del Pozo, A. E. Sorochinsky, S. Fustero, V. A. Soloshonok and H. Liu, *Chem. Rev.*, 2014, **114**, 2432; (f) E. P. Gillis, K. J. Eastman, M. D. Hill, D. J. Donnelly and N. A. Meanwell, *J. Med. Chem.*, 2015, **58**, 8315.

2 For selected reviews, see: (a) T. Liang, C. N. Neumann and T. Ritter, *Angew. Chem., Int. Ed.*, 2013, **52**, 8214; (b) F. Toulgoat, S. Alazet and T. Billard, *Eur. J. Org. Chem.*, 2014, 2415; (c) A. J. Cresswell, S. G. Davies, P. M. Roberts and J. E. Thomson, *Chem. Rev.*, 2015, **115**, 566; (d) J. Charpentier, N. Früh and A. Togni, *Chem. Rev.*, 2015, **115**, 650; (e) X. Liu, C. Xu, M. Wang and Q. Liu, *Chem. Rev.*, 2015, **115**, 683; (f) X.-H. Xu, K. Matsuzaki and N. Shibata, *Chem. Rev.*, 2015, **115**, 731; (g) C. Ni, M. Hu and J. Hu, *Chem. Rev.*, 2015, **115**, 765; (h) T. Ahrens, J. Kohlmann, M. Ahrens and T. Braun, *Chem. Rev.*, 2015, **115**, 931; (i) C. Alonso, E. Martínez de Marigorta, G. Rubiales and F. Palacios, *Chem. Rev.*, 2015, **115**, 1847.

3 (a) W. Sheppard, *J. Am. Chem. Soc.*, 1963, **85**, 1314; (b) C. Hansch, A. Leo and R. W. Taft, *Chem. Rev.*, 1991, **91**, 165; (c) R. Goumont, E. Kizilian, E. Buncel and F. Terrier, *Org. Biomol. Chem.*, 2003, **1**, 1741; (d) F. Terrier, E. Magnier, E. Kizilian, C. Wakselman and E. Buncel, *J. Am. Chem. Soc.*, 2005, **127**, 5563.

4 (a) G. Wang, H. Zhang, J. Zhou, C. Ha, D. Pei and K. Ding, *Synthesis*, 2008, 2398; (b) B. E. Sleebs, P. E. Czabotar, W. J. Fairbrother, W. D. Fairlie, J. A. Flygare, D. C. S. Huang, W. J. A. Kersten, M. F. T. Koehler, G. Lessene, K. Lowes, J. P. Parisot, B. J. Smith, M. L. Smith, A. J. Souers, I. P. Street, H. Yang and J. B. Baell, *J. Med. Chem.*, 2011, **54**, 1914; (c) P. Ondachi, A. Castro, C. W. Luetje, M. I. Damaj, S. W. Mascarella, H. A. Navarro and F. I. Carroll, *J. Med. Chem.*, 2012, **55**, 6512; (d) J.

View Article Online
DOI: 10.1039/C6OB01567K

Chen, H. Zhou, A. Aguilar, L. Liu, L. Bai, D. McEachern, C.-Y. Yang, J. L. Meagher, J. A. Stuckey and S. Wang, *J. Med. Chem.*, 2012, **55**, 8502.

5 (a) K. Ishihara, A. Hasegawa and H. Yamamoto, *Angew. Chem., Int. Ed.*, 2001, **40**, 4077; (b) P. Wu, R. Hilgraf and V. V. Fokin, *Adv. Synth. Catal.*, 2006, **348**, 1079; (c) A. Hasegawa, Y. Naganawa, M. Fushimi, K. Ishihara and H. Yamamoto, *Org. Lett.*, 2006, **8**, 3175; (d) R. Kargbo, Y. Takahashi, S. Bhor, G. R. Cook, G. C. Lloyd-Jones and I. R. Shepperson, *J. Am. Chem. Soc.*, 2007, **129**, 3846; (e) H. Yanai, H. Ogura, H. Fukaya, A. Kotani, F. Kusu and T. Taguchi, *Chem. Eur. J.*, 2011, **17**, 11747; (f) H. Yanai, T. Yoshino, M. Fujita, H. Fukaya, A. Kotani, F. Kusu and T. Taguchi, *Angew. Chem., Int. Ed.*, 2013, **52**, 1560.

6 (a) C. L. Droumaguet, O. Mongin, M. H. V. Werts and M. Blanchard-Desce, *Chem. Commun.*, 2005, 2802; (b) O. Mongin, L. Porrès, M. Charlot, C. Katan and M. Blanchard-Desce, *Chem. Eur. J.*, 2007, **13**, 1481; (c) F. Terenziani, C. L. Droumaguet, C. Katan, O. Mongin and M. Blanchard-Desce, *ChemPhysChem*, 2007, **8**, 723; (d) C. Rouxel, C. L. Droumaguet, Y. Macé, S. Clift, O. Mongin, E. Magnier and M. Blanchard-Desce, *Chem. Eur. J.*, 2012, **18**, 12487.

7 For recent examples, see: (a) R. Pluta, P. Nikolaienko and M. Rueping, *Angew. Chem., Int. Ed.*, 2014, **53**, 1650; (b) G. K. S. Prakash, F. Wang, Z. Zhang, R. Haiges, M. Rahm, K. O. Christe, T. Mathew and G. A. Olah, *Angew. Chem., Int. Ed.*, 2014, **53**, 11575; (c) S. Yoshida, K. Uchida, K. Igawa, K. Tomooka and T. Hosoya, *Chem. Commun.*, 2014, **50**, 15059; (d) S. K. Aithagani, K. R. Yempalla, G. Munagala, R. A. Vishwakarma and P. P. Singh, *RSC Adv.*, 2014, **4**, 50208; (e) Q. Wang, Z. Qi, F. Xie and X. Li, *Adv. Synth. Catal.*, 2015, **357**, 355; (f) F. Xie, Z. Zhang, X. Yu, G. Tang and X. Li, *Angew. Chem., Int. Ed.*, 2015, **54**, 7405; (g) B. Alcaide, P. Almendros, I. Fernández and C. Lázaro-Milla, *Chem. Commun.*, 2015, **51**, 3395; (h) K. Zhang, X.-H. Xu and F.-L. Qing, *J. Org. Chem.*, 2015, **80**, 7658; (i) O. K. Rasheed, I. R. Hardcastle, J. Raftery and P. Quayle, *Org. Biomol. Chem.*, 2015, **13**, 8048; (j) K. Matsuzaki, K. Okuyama, E. Tokunaga, N. Saito, M. Shiro and N. Shibata, *Org. Lett.*, 2015, **17**, 3038; (k) F. Wang, X. Yu, Z. Qi and X. Li, *Chem. Eur. J.*, 2016, **22**, 511; (l) L. A. Smyth, E. M. Phillips, V. S. Chan, J. G. Napolitano, R. Henry and S. Shekhar, *J. Org. Chem.*, 2016, **81**, 1285.

8 For selected examples, see: (a) R. Goumont, K. Magder, M. Tordeux, J. Marrot, F. Terrier and C.Wakselman, *Eur. J. Org. Chem.*, 1999, 2969; (b) T. Billard and B. R. Langlois, *Tetrahedron*, 1999, **55**, 8065; (c) C. Xing and S. Zhu, *J. Org. Chem.*, 2004, **69**, 6486; (d) H. Yanai, M. Fujita and T. Taguchi, *Chem. Commun.*, 2011, **47**, 7245; (e) H. I. Kong, J. E. Crichton and J. M. Manthorpe, *Tetrahedron Lett.*, 2011, **52**, 3714; (f) H. Yanai, S. Egawa and T. Taguchi, *Tetrahedron Lett.*, 2013, **54**, 2160.

9 For selected examples, see: (a) M. Hanack and B. Wilhelm, *Angew. Chem. Int. Ed. Engl.*, 1989, **28**, 1057; (b) I. Ryu, N. Kusumoto, A. Ogawa, N. Kambe and N. Sonoda, *Organometallics*, 1989, **8**, 2279; (c) J. S. Xiang, A. Mahadevan and P. L. Fuchs, *J. Am. Chem. Soc.*, 1996, **118**, 4284; (d) J. Xiang and P. L. Fuchs, *J. Am. Chem. Soc.*, 1996, **118**, 11986; (e) N. Kano, A. Kikuchi and T. Kawashima, *Chem. Commun.*, 2001, 2096; (f) D. Shikanai, H. Murase, T. Hata and H. Urabe, *J. Am. Chem. Soc.*, 2009, **131**, 3166.

10 (a) T. Okauchi, T. Teshima, K. Hayashi, N. Suetsugu and T. Minami, *J. Am. Chem. Soc.*, 2001, **123**, 12117; (b) R. Neumann, H.-G. Herz and G. Maas, *Z. Naturforsch., B: Chem. Sci.*, 2002, **57**, 427; (c) X.-H. Xu, M. Taniguchi, X. Wang, E. Tokunaga, T. Ozawa, H. Masuda and N. Shibata, *Angew. Chem., Int. Ed.*, 2013, **52**, 12628.

11 (a) J. M. Baskin and Z. Wang, *Org. Lett.*, 2002, **4**, 4423; (b) S. Cacchi, G. Fabrizi, A. Goggiamani, L. M. Parisi and R. Bernini, *J. Org. Chem.*, 2004, **69**, 5608; (c) W. Zhu and D. Ma, *J. Org. Chem.*, 2005, **70**, 2696; (d) M. Bian, F. Xu and C. Ma, *Synthesis*, 2007, 2951; (e) F. Huang and R. A. Batey, *Tetrahedron*, 2007, **63**, 7667; (f) B. T. V. Srinivas, V. S. Rawat, K. Konda and B. Sreedhar, *Adv. Synth. Catal.*, 2014, **356**, 805; (g) Y. Xu, J. Zhao, X. Tang, W. Wu and H. Jiang, *Adv. Synth. Catal.*, 2014, **356**, 2029; (h) N. Taniguchi, *Tetrahedron*, 2014, **70**, 1984.

12 (a) B. P. Fors and S. L. Buchwald, *J. Am. Chem. Soc.*, 2009, **131**, 12898; (b) G. Teverovskiy, D. S. Surry, S. L. Buchwald, *Angew. Chem., Int. Ed.*, 2011, **50**, 7312; (c) S. C. Cullen, S. Shekhar and N. K. Nere, *J. Org. Chem.*, 2013, **78**, 12194.

13 (a) Y. Xu, X. Tang, W. Hu, W. Wu and H. Jiang, *Green Chem.*, 2014, **16**, 3720; (b) G. Rong, J. Mao, H. Yan, Y. Zheng and G. Zhang, *J. Org. Chem.*, 2015, **80**, 7652; (c) P. Katrun, S. Hlekhlai, J. Meesin, M. Pohmakotr, V. Reutrakul, T. Jaipetch, D. Soorukram and C. Kuhakarn, *Org. Biomol. Chem.*, 2015, **13**, 4785; (d) J. Meesin, P. Katrun, V. Reutrakul, M. Pohmakotr, D. Soorukram and C. Kuhakarn, *Tetrahedron*, 2016, **72**, 1440.

14 (a) S. Tang, Y. Wu, W. Liao, R. Bai, C. Liu and A. Lei, *Chem. Commun.*, 2014, **50**, 4496; (b) F. Xiao, H. Chen, H. Xie, S. Chen, L. Yang and G.-J. Deng, *Org. Lett.*, 2014, **16**, 50; (c) R. Singh, B. K. Allam, N. Singh, K. Kumari, S. K. Singh and K. N. Singh, *Org. Lett.*, 2015, **17**, 2656; (d) W. Wei, J. Wen, D. Yang, H. Jing, J. You and H. Wang, *RSC Adv.*, 2015, **5**, 4416; (e) N. Zhang, D. Yang, W. Wei, L. Yuan, Y. Cao and H. Wang, *RSC Adv.*, 2015, **5**, 37013; (f) J. Gao, J. Lai and G. Yuan, *RSC Adv.*, 2015, **5**, 66723; (g) Y.-C. Luo, X.-J. Pan and G.-Q. Yuan, *Tetrahedron*, 2015, **71**, 2119; (h) J. Chen, J. Mao, Y. Zheng, D. Liu, G. Rong, H. Yan, C. Zhang and D. Shi, *Tetrahedron*, 2015, **71**, 5059; (i) W. Fan, J. Su, D. Shi and B. Feng, *Tetrahedron*, 2015, **71**, 6740.

15 M. Rueping, N. Tolstoluzhsky and P. Nikolaienko, *Chem. Eur. J.*, 2013, **19**, 14043.

16 When TEMPO was added to the reaction mixture, CF_3SO_2Na (δ = −88.8 ppm, s) was converted to a new product (δ = −79.2 ppm, s), probably CF_3SO_3Na, according to the ^{19}F NMR spectroscopy.

17 (a) S. Minakata and J. Hayakawa, *Chem. Commun.*, 2011, **47**, 1905; (b) M. A. Kumar, P. Swamy, M. Naresh, M. M. Reddy, C. N. Rohitha, S. Prabhakar, A. V. S. Sarma, J. R. P. Kumar and N. Narender, *Chem. Commun.*, 2013, **49**, 1711; (c) W. Z. Yu, F. Chen, Y. A. Cheng and Y.-Y. Yeung, *J. Org. Chem.*, 2015, **80**, 2815; (d) K. Sun, F. Ma, L. Liu, J. Sun, X. Liu, Y. Wang, Z. Zhang and G. Zhang, *RSC Adv.*, 2015, **5**, 82492; (e) B. A. Shainyan, M. Y. Moskalik, V. V. Astakhova, I. V. Sterkhova and I. A. Ushakov, *Tetrahedron*, 2015, **71**, 8669; (f) H. Egami, T. Yoneda, M. Uku, T. Ide, Y. Kawato and Y. Hamashima, *J. Org. Chem.*, 2016, **81**, 4020.