C–C Bond Formation

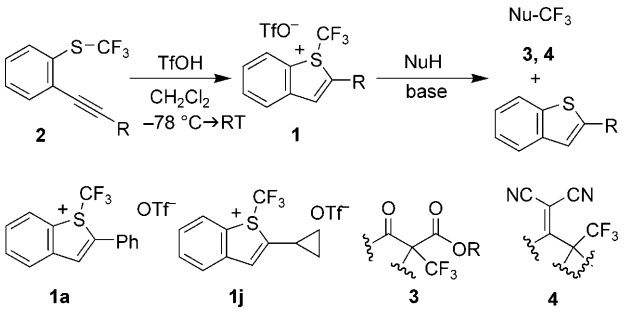
DOI: 10.1002/anie.200905225

Efficient Access to Extended Yagupolskii–Umemoto-Type Reagents: Triflic Acid Catalyzed Intramolecular Cyclization of *ortho*-Ethynylaryltrifluoromethylsulfanes**

*Andrej Matsnev, Shun Noritake, Yoshinori Nomura, Etsuko Tokunaga, Shuichi Nakamura, and Norio Shibata**

In memory of Lev Moiseevich Yagupolskii

Trifluoromethylation is one of the most direct and straightforward strategies in the synthesis of fluorine-containing organic compounds, which are sought after building blocks in the development of pharmaceuticals and agrochemicals.[1] The reagents involved in transferring a trifluoromethyl group onto a target molecule are classified according to their nucleophilic or electrophilic character. Whilst the nucleophilic trifluoromethylation reaction is well known, exemplified by the use of trifluoromethyltrimethylsilane (Me_3SiCF_3), the development of electrophilic trifluoromethylation remains a challenge.[2] In 1984, Yagupolskii and coworkers discovered that *S*-(trifluoromethyl)diarylsulfonium salts are effective for the trifluoromethylation of thiophenolates.[3] Since then, the design and synthesis of electrophilic trifluoromethylating reagents has been extensively researched.[4] Of the reagents that have been developed, the *S*-(trifluoromethyl)dibenzothiophenium salts designed by Umemoto[1b] and Thayer[1c] have emerged as among the most powerful tools for this purpose, and are effective for the trifluoromethylation of a wide range of nucleophiles. Although several Umemoto reagents are commercially available, their use, and those of related reagents, suffers from their relatively complex synthesis. Magnier and coworkers developed a more straightforward, efficient one-pot synthesis of *S*-(trifluoromethyl)dibenzothiophenium salts.[5] Recently, Togni et al. reported the electrophilic trifluoromethylation of carbon- or heteroatom-centered nucleophiles using a mild hypervalent iodine(III)trifluoromethyl reagent.[6] This reagent effects the trifluoromethylation of a range of nucleophiles, and is now commercially available. In 2008, we reported a fluorinated Johnson-type reagent for the electrophilic trifluoromethylation of carbon-centered nucleophiles;[7] this reagent is also now commercially available[8] and is effective for the trifluoromethylation of cyclic β-keto esters and dicyanoalkylidenes. However, the reactivity towards acyclic substrates is unsatisfactory and, as such, more effective reagents are required for the trifluoromethylation of carbon nucleophiles. In connection with our interest in the synthesis of organofluorine compounds,[9] we herein report a straightforward route to extended Yagupolskii–Umemoto-type reagents, *S*-(trifluoromethyl)thiophenium salts **1**, through the triflic acid catalyzed intramolecular cyclization of *ortho*-ethynylaryltrifluoromethylsulfanes **2** (Scheme 1). 2-Phenylthiophenium salt **1a** and 2-cyclopropylthiophenium salt **1j** were selected to evaluate the scope of the trifluoromethylation reaction of β-ketoesters and dicyanoalkylidenes. The best results were obtained for trifluoromethylations using **1j** that afforded a quaternary carbon center, **3** and **4**, even with substrates that have an unreactive acyclic system.



Scheme 1. Triflic acid catalyzed synthesis of *S*-(trifluoromethyl)thiophenium salts and their use in trifluoromethylations.

Cyclization of *ortho*-substituted aryl alkynes has received interest recently in areas ranging from material sciences to pharmaceuticals. Metal salts or acids have been used to induce the cyclization of alkynes to obtain five-membered rings and heterocycles.[10] However, the synthesis of *S*-(trifluoromethyl)benzo[b]thiophenium salts using these methods has not been reported, despite their potential usefulness as trifluoromethylating reagents and wide applicability as building blocks for the synthesis of biologically active compounds.[11,12] Although recent rapid progress in the coinage-metal-catalyzed cyclization[13] of *ortho*-thio-substituted aryl alkynes has allowed easy access to benzothio-

[*] A. Matsnev, S. Noritake, Y. Nomura, E. Tokunaga, Dr. S. Nakamura, Prof. N. Shibata
Department of Frontier Materials, Graduate School of Engineering, Nagoya Institute of Technology
Gokiso, Showa-ku, Nagoya 466-8555 (Japan)
Fax: (+81) 52-735-7543
E-mail: nozshiba@nitech.ac.jp

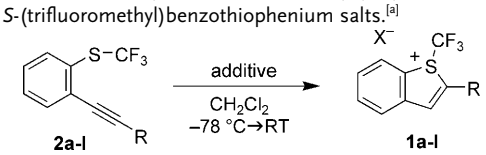
[**] Support was provided by KAKENHI (21390030). We also thank TOSOH F-TECH INC. We are grateful to Central Glass Co., Ltd. for the gift of trifluoromethanesulfinate.

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/anie.200905225.

phenes, this method is not suitable for the synthesis of benzothiophenium salts. In 1994, Kitamura and co-workers reported the cyclization of *o*-SPh-substituted aryl alkynes using HBF_4 or $HClO_4$ that afforded cyclized 1-phenyl-1-benzothiophenium salts.[14] However, under the same conditions, *o*-SMe-substituted alkynes gave de-methylated benzo[b]thiophenes, and *S*-methyl salts were not detected. Electrophilic cyclization using reagents such as I_2, Br_2, and PhSeCl also gave the corresponding benzo[b]thiophenes through a demethylation pathway.

Initially, we attempted the cyclization reaction of **2a** to **1a** using coinage metal salts. However, neither gold salts nor copper salts afforded a trifluoromethyl-substituted, five-membered ring under analogous literature conditions (Table 1, entries 1–4). Therefore, we turned our attention to the Brønsted acid catalyzed cyclization reaction; however, neither HBF_4 nor $HClO_4$ were effective for this transformation (Table 1, entries 5 and 6). In contrast, triflic acid (CF_3SO_3H, TfOH) was extremely efficient in affording the desired product **2a** in 79% yield (Table 1, entry 7).[15] The scope of this procedure was then considered for a wide range of *ortho*-substituted alkynes, and the cyclized product was obtained efficiently in almost all cases (Table 1, entries 8–17). The annulation of a broad range of *o*-SCF_3-substituted aryl alkynes that have functionalized aromatic rings afforded their corresponding *S*-(trifluoromethyl)thiophenium salts in good to excellent yields (64–94%; Table 1, entries 8–14). No CF_3 migration, often observed for the cyclization to *S*-phenyl, methyl, or related alkylthiophenium salts,[10–14] was observed within the ring. Annulation of benzyl-substituted alkyne **1i** with TfOH gave a complex mixture of products, presumably owing to the deprotonation/de-trifluoromethylation of **1i** into **A** (Table 1, entry 15; Scheme 2). Cyclopropyl-substituted alkyne **2j** was converted into the corresponding *S*-(trifluoromethyl)thiophenium salt **1j** in good yield without any loss of the trifluoromethyl group (80%; Table 1, entry 16). Deprotonation of the product was presumably impeded by the sterically bulky cyclopropane moiety. Indeed, *tert*-butyl alkyne **2k** also gave a good result, giving the product in 64% yield (Table 1, entry 17). Moreover, even C_2-symmetric substrate **2l** was successfully transformed into the corresponding dicationic salt **1l** through a double cyclization reaction (Table 1, entry 18; Scheme 2). These are the first reported examples of the preparation of *S*-(trifluoromethyl)-benzothiophenium salts.

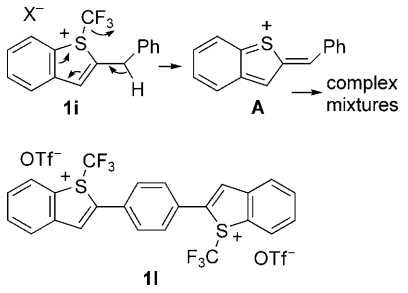
Table 1: Intramolecular cyclization of *ortho*-ethynylaryltrifluoromethylsulfane to *S*-(trifluoromethyl)benzothiophenium salts.[a]



2a-l **1a-l**

Entry	2	R	Additive (equiv)	1	Yield[b] [%]
1	**2a**	Ph	$[Au(PPh_3)_2Cl]$ (0.1)[c]	**1a**	0
2	**2a**	Ph	$AuCl_3$ (0.1)[c]	**1a**	0
3	**2a**	Ph	$CuCl_2$ (0.1)[c]	**1a**	0
4	**2a**	Ph	$CuBr_2$ (0.1)[c]	**1a**	0
5	**2a**	Ph	HBF_4 (2.5)[c]	**1a**	0
6	**2a**	Ph	$HClO_4$ (2.5)[c]	**1a**	0
7	**2a**	Ph	TfOH (2.0)	**1a**	79
8	**2b**	*p*-MeC_6H_4	TfOH (2.0)	**1b**	94
9	**2c**	*m*-BrC_6H_4	TfOH (2.0)	**1c**	87
10	**2d**	*p*-BrC_6H_4	TfOH (2.0)	**1d**	82
11	**2e**	*p*-$MeOC_6H_4$	TfOH (2.0)	**1e**	73
12	**2f**	*o*-ClC_6H_4	TfOH (2.0)	**1f**	64
13	**2g**	*o,p-di*-FC_6H_3	TfOH (2.0)	**1g**	72
14	**2h**	*p*-IC_6H_4	TfOH (2.0)	**1h**	78
15	**2i**	CH_2Ph	TfOH (2.0)	**1i**	0[d]
16	**2j**	cyclopropyl	TfOH (2.0)	**1j**	80
17	**2k**	*t*Bu	TfOH (2.0)	**1k**	64
18	**2l**	*p*-C_6H_4-C≡C-*o*-C_6H_4-SCF_3	TfOH (2.0)	**1l**[e]	68

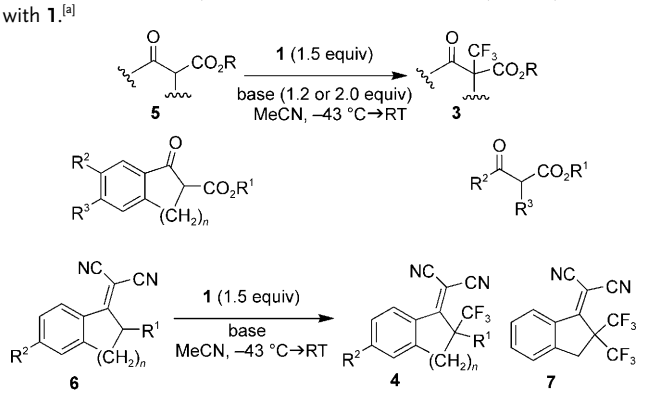
[a] The cyclization of **2** into **1** was carried out in the presence of TfOH (2 equiv) in solvent at −78 °C. For detailed reaction conditions, see the Supporting Information. [b] Yield of isolated product. [c] For experimental details of unsuccessful reactions, see the Supporting Information. [d, e] See Scheme 2.



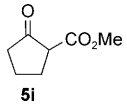
Scheme 2. De-trifluoromethylation of **1i** and double cyclization to afford **1l**.

Following the synthesis of various *S*-(trifluoromethyl)thiophenium salts **1**, the electrophilic trifluoromethylation of a wide range of carbon nucleophiles to afford their corresponding trifluoromethylated compounds with a quaternary carbon center was examined. As many important biologically active compounds contain quaternary carbon centers, this procedure would be particularly attractive to both organic and medicinal chemists. Salts **1a** and **1j** were selected to evaluate the effectiveness of the *S*-(trifluoromethyl)thiophenium reagents with aryl (**1a**) or alkyl (**1j**) substituents. Cyclic and acyclic β-keto esters afforded their corresponding trifluoromethylated compounds, which had a quaternary carbon center, in good to high yields in the presence of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) or *tert*-butyliminotri(pyrrolidino)phosphorane (P_1) as the base (59–95%; Table 2, entries 1–25). Cyclopropyl-substituted reagent **1j** afforded slightly improved yields compared to when phenyl-substituted **1a** was used (Table 2, entries 1–6 versus 7–14). Cyclopropyl reagent **1j** presents a clear advantage of higher yields over both the aromatic analogue (**1a**) and the commercially available Umemoto reagent (*S*-(trifluoromethyl)dibenzothiophenium tetrafluoroborate) in the trifluoromethylation of acyclic β-keto esters (Table 2, entries 15–17). Good to high yields of trifluoromethylated acyclic β-keto esters were obtained more

Table 2: Trifluoromethylation of β-keto esters **5** or dicyanoalkylidenes **6** with **1**.[a]



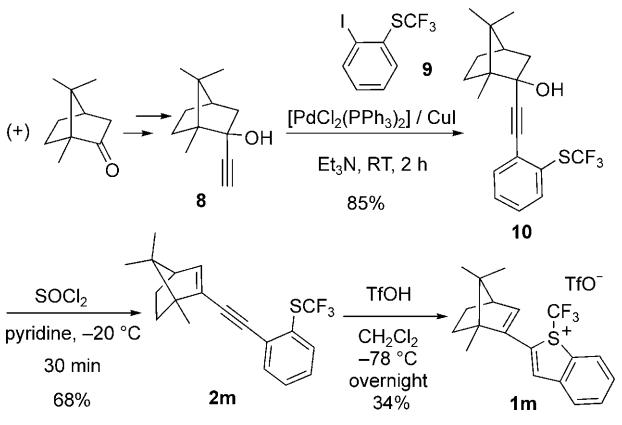
6a: R^1=H, R^2=H, *n*=2; **6b**: R^1=H, R^2=OMe, *n*=2
6c: R^1=H, R^2=H, *n*=1; **6d**: R^1=Me, R^2=H, *n*=1; **6e**: R^1=Me, R^2=Cl, *n*=1

Entry		**5** or **6**	Base (equiv)	**1**	**3** or **4**	Yield[b] [%]
1	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**1a**	**3a**	76
2	R^1 = Bn, R^2 = R^3 = H, *n* = 1	**5b**	DBU (1.2)	**1a**	**3b**	82
3	R^1 = *t*Bu, R^2 = R^3 = H, *n* = 1	**5c**	DBU (1.2)	**1a**	**3c**	80
4	R^1 = *t*Bu, R^2 = H, R^3 = Br, *n* = 1	**5d**	DBU (1.2)	**1a**	**3d**	79
5	R^1 = Me, R^2 = R^3 = OMe, *n* = 1	**5e**	DBU (1.2)	**1a**	**3e**	59
6	R^1 = Me, R^2 = R^3 = H, *n* = 2	**5f**	DBU (1.2)	**1a**	**3f**	80
7	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**1j**	**3a**	92
8	R^1 = Bn, R^2 = R^3 = H, *n* = 1	**5b**	DBU (1.2)	**1j**	**3b**	89
9	R^1 = *t*Bu, R^2 = R^3 = H, *n* = 1	**5c**	DBU (1.2)	**1j**	**3c**	78
10	R^1 = *t*Bu, R^2 = H, R^3 = Br, *n* = 1	**5d**	DBU (1.2)	**1j**	**3d**	91
11	R^1 = Me, R^2 = R^3 = H, *n* = 2	**5f**	DBU (2.0)	**1j**	**3f**	82
12	R^1 = *t*Bu, R^2 = R^3 = H, *n* = 2	**5g**	DBU (2.0)	**1j**	**3g**	95
13	R^1 = Me, R^2 = H, R^3 = OMe, *n* = 2	**5h**	DBU (2.0)	**1j**	**3h**	92
14	 **5i**	**5i**	DBU (2.0)	**1j**	**3i**	60
15	R^1 = Bn, R^2 = Et, R^3 = Me	**5j**	P_1 (2.0)	**1a**	**3j**	60
16	R^1 = Bn, R^2 = Et, R^3 = Me	**5j**	P_1 (2.0)	**1j**	**3j**	84
17	R^1 = Bn, R^2 = Et, R^3 = Me	**5j**	P_1 (2.0)	**UR**	**3j**	59
18	R^1 = Et, R^2 = Me, R^3 = Bn	**5k**	P_1 (2.0)	**1j**	**3k**	70
19	R^1 = *t*Bu, R^2 = Me, R^3 = Et	**5l**	P_1 (2.0)	**1j**	**3l**	68 (86)[c]
20	R^1 = Et, R^2 = Ph, R^3 = Me	**5m**	P_1 (2.0)	**1j**	**3m**	87
21	R^1 = Et, R^2 = Me, R^3 = Et	**5n**	P_1 (2.0)	**1j**	**3n**	44 (69)[c]
22	R^1 = Et, R^2 = Ph, R^3 = Et	**5o**	P_1 (2.0)	**1j**	**3o**	84
23	R^1 = Et, R^2 = Ph, R^3 = Pr	**5p**	P_1 (2.0)	**1j**	**3p**	71
24	R^1 = Et, R^2 = Pr, R^3 = Bn	**5q**	P_1 (2.0)	**1j**	**3q**	83
25	R^1 = $CHPh_2$, R^2 = Et, R^3 = Me	**5r**	P_1 (2.0)	**1j**	**3r**	67
26		**6a**	P_1 (1.2)	**1j**	**4a**	89
27		**6b**	P_1 (1.2)	**1j**	**4b**	90
28		**6c**	P_1 (2.2)	**1j**	**4c**+**7**	75[c] (**4c**:**7** = 1:24)
29		**6d**	DBU (1.2)	**1j**	**4d**	93
30		**6e**	DBU (1.2)	**1j**	**4e**	91
31	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**1b**	**3a**	83
32	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**1g**	**3a**	78
33	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**1k**	**3a**	88
34	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	DBU (1.2)	**TR**	**3a**	17
35	R^1 = Bn, R^2 = Et, R^3 = Me	**5j**	P_1 (2.0)	**TR**	**3j**	trace
36	R^1 = Me, R^2 = R^3 = H, *n* = 1	**5a**	K_2CO_3[d]	**TR**	**3a**	42[d]

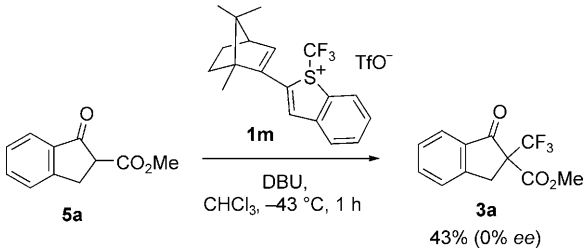
[a] P_1: *tert*-butyliminotri(pyrrolidino)phosphorane; UR: Umemoto reagent, *S*-(trifluoromethyl)dibenzothiophenium tetrafluoroborate; TR: Togni's reagent (1-trifluoromethyl-3,3-dimethyl-1,2-benziodoxole). The reaction of either substrate **5** or **6** with **1** (1.5 equiv) was carried out in the presence of a base (1.2–2.0 equiv) in MeCN at −43–−45 °C. For detailed reaction conditions, see the Supporting Information. [b] Yield of isolated product. [c] 2.4 Equivalents of **1j** used. Yield determined by ^{1}H NMR spectroscopy. [d] Reaction performed in the presence of nBu_4NI in MeCN. These data were taken from reference [6a,b].

or less independent of the substrate structure (Table 2, entries 18–25). The reagent **1j** was also found to be effective for the trifluoromethylation of dicyanoalkylidenes **6a–e**, under similar conditions, to afford allylic trifluoromethylated compounds **4a–e** and **7** (Table 2, entries 26–30). To understand the higher yields obtained with **1j** over **1a**, and the influence of substituents, reagents **1b**, **1g**, and **1k** were also evaluated and their results compared. The trifluoromethylation of **5a** with **1b**, **1g**, and **1k** also proceeded well to furnish product **3a** in 83%, 78%, and 88% yields, respectively (Table 2, entries 31–33). These results indicate that reagents containing alkyl substituents tend to afford the product in slightly higher yields than those containing aryl substituents. Although the reason for the improved yield is not clear, it is presumably due to the stability of the reagents: aryl-substituted reagents have better CF_3 releasing ability owing to the stability of the benzothiophene derivative by-product, as a consequence of the conjugated structures, whereas alkyl-substituted trifluoromethylated reagents are more stable than their aryl-substituted counterparts. High reactivity might be ineffective for this trifluoromethylation reaction because of the competitive decomposition under basic conditions. A brief comparison to Togni's reagent, which is also commercially available and is a competitor to the Umemoto reagent, was also performed. Under our reaction conditions, the yields of trifluoromethylated products **3a** and **3j** with Togni's reagent were lower than those using **1j** (Table 2, entries 34 and 35, versus 7 and 16, respectively). However, these comparisons might not be fair because a higher yield (42%) was reported under different conditions (Table 2, entry 36),[6a,b] and might be improved by further optimization.

One advantage of our new trifluoromethylation reagents **1** is the potential functionalization at the thiophene 2-position with chiral groups that offers the possibility of enantioselective trifluoromethylation of prochiral substrates, one of the important unresolved issues of fluoroorganic synthesis. Therefore, chiral reagent **1m** was designed and synthesized, and its preparation is shown in Scheme 3. (1*R*,2*S*,4*R*)-2-Ethynyl-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol **8**,[16] prepared from (1*R*)-(+)-camphor, was treated with 2-iodophenyl(trifluoromethyl)sulfane **9** under Sonogashira coupling conditions to furnish **10** in 85% yield. Dehydration of **10** was achieved in the presence of $SOCl_2$ to give enyne **2m** in 68% yield. Our triflic acid catalyzed intramolecular cyclization was performed on **2m** to afford the target chiral reagent **1m** in 34% yield as a 1:1 mixture of diastereoisomers, which are racemic at the sulfur atom (Scheme 3). Compound **1m** was characterized by spectroscopy and elemental analysis; however, a satisfactory ^{1}H NMR spectrum could not be obtained owing to slight decomposition of **1m**, especially in $CDCl_3$. The decomposition of **1m** was minimized in CD_3CN. The trifluoromethylation of **5a** by **1m** was then performed in the presence of DBU under the same reaction conditions to furnish the trifluoromethylated product **3a** in 43% yield, regrettably as a racemate (Scheme 4).



Scheme 3. Synthesis of chiral reagent **1m**.



Scheme 4. Attempted enantioselective trifluoromethylation of **5a** by chiral reagent **1m**. DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene.

In conclusion, we have described the straightforward synthesis of *S*-(trifluoromethyl)thiophenium salts by the triflic acid catalyzed intramolecular cyclization of *ortho*-ethynylaryltrifluoromethylsulfanes without migration or loss of the CF_3 group. These salts are promising as extended Yagupolskii–Umemoto reagents for the electrophilic trifluoromethylation of carbon-centered nucleophiles, including β-keto esters and dicyanoalkylidenes. Furthermore, cyclopropyl-substituted reagent **1j** has advantages over the Umemoto reagents.

Received: September 18, 2009
Revised: October 29, 2009
Published online: December 15, 2009

Keywords: C–C bond formation · cyclization · fluorine · triflic acid · trifluoromethylation

[1] a) P. Kirsch, *Modern Fluoroorganic Chemistry*; Wiley-VCH, Weinheim, **2004**; b) T. Umemoto, *Chem. Rev.* **1996**, *96*, 1757–1777; c) A. M. Thayer, *Chem. Eng. News* **2006**, *84*, 15–24.

[2] a) G. K. S. Prakash, A. K. Yudin, *Chem. Rev.* **1997**, *97*, 757–786; b) R. P. Shigh, J. M. Shreeve, *Tetrahedron* **2000**, *56*, 7613–7632; c) T. Billard, B. R. Langlois, *Eur. J. Org. Chem.* **2007**, 891–897; d) J.-A. Ma, D. Cahard, *Chem. Rev.* **2008**, *108*, PR1–PR43; e) N. Shibata, S. Mizuta. T. Toru, *J. Synth. Org. Chem. Jpn.* **2008**, *66*, 215–218; f) N. Shibata, S. Mizuta, H. Kawai, *Tetrahedron: Asymmetry* **2008**, *19*, 2633–2644.

[3] L. M. Yagupol'skii, N. V. Kondratenko, G. N. Timofeeva, *J. Org. Chem. USSR* **1984**, *20*, 103–106.

[4] a) T. Umemoto, S. Ishihara, *Tetrahedron Lett.* **1990**, *31*, 3579–3582; b) T. Umemoto, S. Ishihara, *J. Am. Chem. Soc.* **1993**, *115*, 2156–2164; c) J.-J. Yang, R. L. Kirchmeier, J. M. Shreeve, *J. Org.*

Chem. **1998**, *63*, 2656 – 2660; d) L. M. Yagupolskii, V. A. Matsnev, R. K. Orlova, B. G. Deryabkin, Y. L. Yagupolskii, *J. Fluorine Chem.* **2008**, *129*, 131 – 136; e) L. M. Yagupolskii, I. I. Maletina, N. V. Kondratenko, V. V. Orda, *Synthesis* **1978**, 835 – 837.

[5] a) E. Magnier, J. C. Blazejewski, M. Tordeux, C. Wakselman, *Angew. Chem.* **2006**, *118*, 1301 – 1304; *Angew. Chem. Int. Ed.* **2006**, *45*, 1279 – 1282; b) Y. Macé, B. Raymondeau, C. Pradet, J.-C. Blazejewski, E. Magnier, *Eur. J. Org. Chem.* **2009**, 1390 – 1397.

[6] a) P. Eisenberger, S. Gischig, A. Togni, *Chem. Eur. J.* **2006**, *12*, 2579 – 2586; b) I. Kieltsch, P. Eisenberger, A. Togni, *Angew. Chem.* **2007**, *119*, 768 – 771; . *Chem. Int. Ed.* **2007**, *46*, 754 – 757; c) P. Eisenberger, I. Kieltsch, N. Armanino, A. Togni, *Chem. Commun.* **2008**, *13*, 1575 – 1577; d) I. Kieltsch, P. Eisenberger, K. Stanek, A. Togni, *Chimia* **2008**, *62*, 260 – 263; e) K. Stanek, R. Koller, A. Togni, *J. Org. Chem.* **2008**, *73*, 7678 – 7685; f) R. Koller, K. Stanek, D. Stolz, R. Aardoom, K. Niedermann, R. Koller, A. Togni, *Angew. Chem.* **2009**, *121*, 4396 – 4400; *Angew. Chem. Int. Ed.* **2009**, *48*, 4332 – 4336; g) R. Koller, Q. Huchet, P. Battaglia, J.-M. Welch, A. Togni, *Chem. Commun.* **2009**, 5993 – 5995.

[7] S. Noritake, N. Shibata, S. Nakamura, T. Toru, M. Shiro, *Eur. J. Org. Chem.* **2008**, 3465 – 3468.

[8] Tokyo Chemical Industry Co. , Ltd. , O0366 R-5093, **2009**.

[9] a) N. Shibata, *J. Synth. Org. Chem. Jpn.* **2006**, *64*, 14 – 24; b) N. Shibata, T. Ishimaru, S. Nakamura, T. Toru, *J. Fluorine Chem.* **2007**, *128*, 469 – 483; c) N. Shibata, E. Suzuki, T. Asahi, M. Shiro, *J. Am. Chem. Soc.* **2001**, *123*, 7001 – 7009; d) N. Shibata, J. Kohno, K. Takai, T. Ishimaru, S. Nakamura, T. Toru, S. Kanemasa, *Angew. Chem.* **2005**, *117*, 4276 – 4279; *Angew. Chem. Int. Ed.* **2005**, *44*, 4204 – 4207; e) D. S. Reddy, N. Shibata, J. Nagai, S. Nakamura, T. Toru, *Angew. Chem.* **2008**, *120*, 170 – 174; *Angew. Chem. Int. Ed.* **2008**, *47*, 164 – 168; f) T. Fukuzumi, N. Shibata, M. Sugiura, H. Yasui, S. Nakamura, T. Toru, *Angew. Chem.* **2006**, *118*, 5095 – 5099; *Angew. Chem. Int. Ed.* **2006**, *45*, 4973 – 4977; g) S. Mizuta, N. Shibata, Y. Goto, T. Furukawa, S. Nakamura, T. Toru, *J. Am. Chem. Soc.* **2007**, *129*, 6394 – 6395; h) S. Mizuta, N. Shibata, S. Akiti, H. Fujimoto, S. Nakamura, T. Toru, *Org. Lett.* **2007**, *9*, 3707 – 3710; i) S. Noritake, N. Shibata, Y. Nomura, Y. Huang, A. Matsnev, S. Nakamura, T. Toru, D. Cahard, *Org. Biomol. Chem.* **2009**, *7*, 3599 – 3604.

[10] a) R. C. Larock in *Acetylene Chemistry. Chemistry, Biology, and Material Science* (Eds.: F. Diederich, P. J. Stang, R. R. Tykwinski), Wiley-VCH, New York, **2005**, chap. 2, pp. 51 – 99; b) R. C. Larock, *Top. Organomet. Chem.* **2005**, *14*, 147 – 182.

[11] R. C. Larock, D. Yue, *Tetrahedron Lett.* **2001**, *42*, 6011 – 6013.

[12] a) C. D. Jones, M. G. Jevnikar, A. J. Pike, M. K. Peters, L. J. Black, A. R. Thompson, J. F. Falcone, J. A. Clemens, *J. Med. Chem.* **1984**, *27*, 1057 – 1066; b) M. Raga, C. Palacin, J. M. Castello, J. A. Ortiz, M. R. Cuberes, M. Moreno-Manas, *Eur. J. Med. Chem.* **1986**, *21*, 329 – 332.

[13] a) I. Nakamura, T. Sato, Y. Yamamoto, *Angew. Chem.* **2006**, *118*, 4585 – 4587; *Angew. Chem. Int. Ed.* **2006**, *45*, 4473 – 4475; b) I. Nakamura, T. Sato, M. Terada, Y. Yamamoto, *Org. Lett.* **2008**, *10*, 2649 – 2651.

[14] T. Kitamura, T. Takachi, M. Miyaji, H. Kawasato, H. Taniguchi, *J. Chem. Soc. Perkin Trans. 1* **1994**, 1907 – 1911.

[15] Just before the completion of this work, triflic acid catalyzed synthesis of spirocyles has appeared. T. Jin, M. Himuro, Y. Yamamoto, *Angew. Chem.* **2009**, *121*, 6007 – 6010; *Angew. Chem. Int. Ed.* **2009**, *48*, 5893 – 5896.

[16] J. H. Kaldis, P. Morawietz, M. J. McGlinchey, *Organometallics* **2003**, *22*, 1293 – 1301.

