Trifluoromethylation

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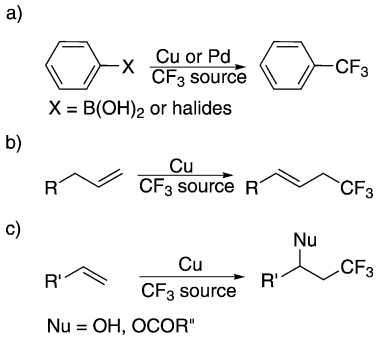
# Copper-Catalyzed Tandem Trifluoromethylation/Semipinacol Rearrangement of Allylic Alcohols**

*Zhi-Min Chen, Wei Bai, Shao-Hua Wang, Bin-Miao Yang, Yong-Qiang Tu,* and Fu-Min Zhang*

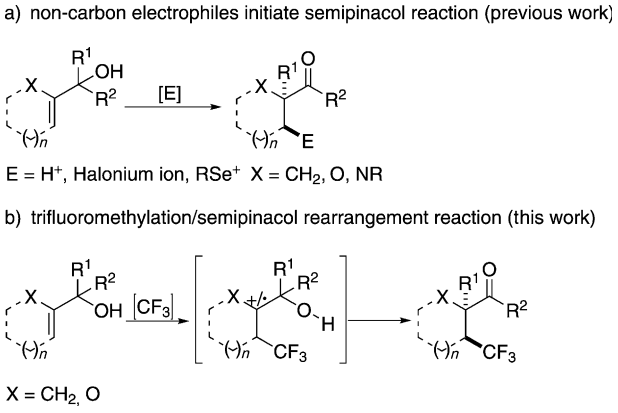
Compounds bearing a trifluoromethyl group have useful properties for agricultural, functional materials, and pharmaceutical applications, mainly because of their metabolic stability, binding selectivity, and lipophilicity.[1] For this reason, there is extensive interest in the development of synthetic methods for constructing C–$CF_3$ bonds.[2,3] Therefore, considerable effort has been made towards the α-trifluoromethylation of carbonyl compounds[4] and the trifluoromethylation of arenes and heteroarenes.[5] For example, asymmetric α-trifluoromethylation of carbonyls has been realized, and transition-metal-mediated or -catalyzed trifluoromethylations of aryl halides or arylboronic acids have been widely studied (Scheme 1a).[6,7] In contrast, strategies for the




***Scheme 1.*** Previous metal-catalyzed trifluoromethylation reactions.

preparation of β-trifluoromethylcarbonyl compounds, which are potentially useful in organofluorine chemistry,[8] remain rare. Similarly, the trifluoromethylation of alkenes to construct $C_{sp^3}$–$CF_3$ bonds have received less attention and are still underexplored.[9] Recently, the trifluoromethylation of terminal alkenes to form allylic $C_{sp^3}$–$CF_3$ bonds was reported by the groups of Buchwald, Liu, Wang, and Qing (Scheme 1b).[10] More recently, a copper-catalyzed trifluoromethylation of alkenes, leading to C–O bond formation, has been developed by the groups of Szabó, Loh, Buchwald, and Sodeoka (Scheme 1c).[11] However, to the best of our knowledge, only a few examples of transition-metal-catalyzed difunctionalization of alkenes involving tandem $C_{sp^3}$–$CF_3$ and carbon-carbon bond formation have been documented.[12] The development of new methods involving a difunctionalization-type trifluoromethylation of alkenes is therefore still highly desirable.

As a powerful strategy for forming α-quaternary carbonyl structures, the semipinacol rearrangement of allylic alcohols plays an important role in the total syntheses of natural products.[13] These rearrangement reactions have been widely studied.[14,15] Strong electrophiles such as $Cl^+$, $Br^+$, $I^+$, and $H^+$ are commonly used as promoters for these rearrangements (Scheme 2a). However, similar intermolecular rearrangements initiated by carbon electrophiles, which can provide more complex carbon frameworks and have been an active project for our group, still remain a challenge.[16] This is attributed to the low electrophilic reactivity of carbon electrophiles toward C=C bonds. Based on recent progress in trifluoromethylation reactions, and combined with our research interests, we thought that electrophilic $CF_3$ reagents might be able to undergo electrophilic addition to allylic alcohols to initiate a semipinacol rearrangement, affording α-quaternary β-trifluoromethyl ketones under certain conditions (Scheme 2b). Furthermore, $C_{sp^3}$–$CF_3$ and carbon–carbon bonds are simultaneously constructed through this strategy. Herein, we present the first tandem trifluoromethylation/semipinacol rearrangement, which could provide important information on the chemistry of fluorination and the semipinacol rearrangement.




***Scheme 2.*** Design of the trifluoromethylation/semipinacol rearrangement reaction.

[*] Z.-M. Chen, W. Bai, S.-H. Wang, B.-M. Yang, Prof. Y.-Q. Tu, F.-M. Zhang
State Key Laboratory of Applied Organic Chemistry and College of Chemistry and Chemical Engineering, Lanzhou University
Lanzhou 730000 (P. R. China)
E-mail: tuyq@lzu.edu.cn

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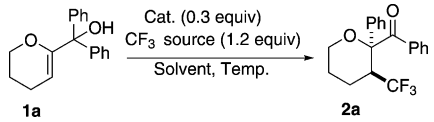
In our initial investigation, 2-oxa allylic alcohol **1a** was chosen as a model substrate. As shown in Table 1, various commercially available copper catalysts were first examined, using Togni's reagent **A**[17] as the $CF_3$ source. Among these

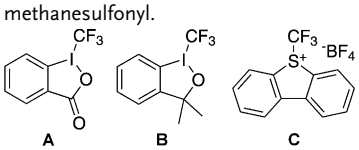
***Table 1:*** Optimization of Trifluoromethylation/Semipinacol Rearrangement Reaction.[a]




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

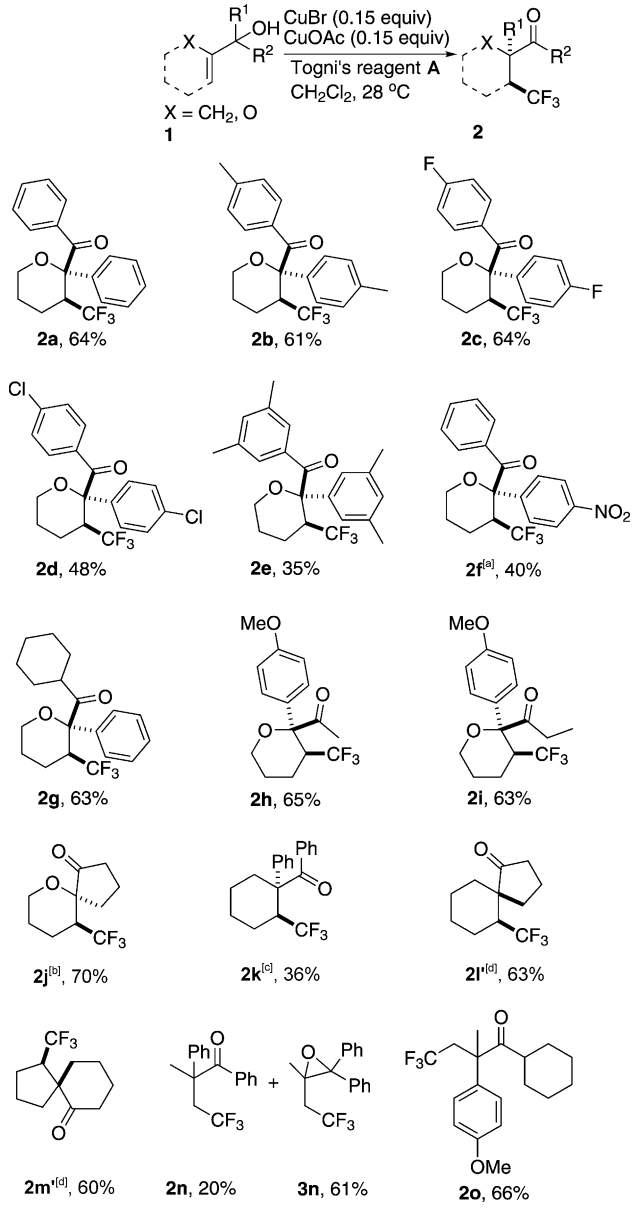
| Entry | Catalyst | $CF_3$ source | Solvent | Yield [%][b] |
|---|---|---|---|---|
| 1 | CuOTf·0.5 $C_6H_6$ | **A** | $CH_2Cl_2$ | 12 |
| 2 | $[(MeCN)_4Cu]PF_6$ | **A** | $CH_2Cl_2$ | 15 |
| 3 | CuCl | **A** | $CH_2Cl_2$ | 34 |
| 4 | CuBr | **A** | $CH_2Cl_2$ | 40 |
| 5 | CuOAc | **A** | $CH_2Cl_2$ | 47 |
| 6 | CuOAc | **B** | $CH_2Cl_2$ | trace |
| 7 | CuOAc | **C** | $CH_2Cl_2$ | – |
| 8 | CuOAc | **A** | $CH_3CN$ | – |
| 9 | CuOAc | **A** | $CH_3OH$ | – |
| 10 | CuOAc | **A** | DCE | 45 |
| 11 | CuOAc | **A** | toluene | n.r. |
| 12[c] | CuBr, CuOAc | **A** | $CH_2Cl_2$ | 54 |
| 13[c,d] | CuBr, CuOAc | **A** | $CH_2Cl_2$ | 64 |
| 14[c,d,e] | CuBr, CuOAc | **A** | $CH_2Cl_2$ | n.r. |
| 15[c,d,f] | CuBr, CuOAc | **A** | $CH_2Cl_2$ | 41 |

[a] All reactions unless specially notified were performed with **1a** (0.1 mmol) and the $CF_3$ reagent (1.2 equiv) in solvent (1.0 mL) at 28 °C. [b] Yield of isolated product. [c] The catalysts CuOAc (0.015 mmol) and CuBr (0.015 mmol) were used. [d] Togni's reagent **A** (1.5 equiv) was used. [e] The reaction was carried out at 0 °C. [f] The reaction was carried out at 40 °C. DCE = 1,2-dichloroethane, n.r. = no reaction, Tf = trifluoromethanesulfonyl.



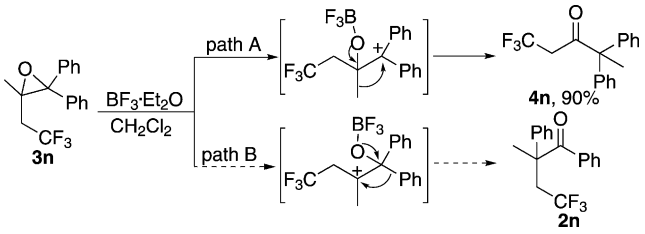

(entries 1–5), a catalytic amount of CuOAc and 1.2 equiv of **A** in $CH_2Cl_2$ at 28 °C gave the best results and produced **2a** in 47 % yield. Next, other $CF_3$ source reagents, Togni's reagent **B** and Umemoto's reagent **C**,[18] were used in this reaction. Unfortunately, only a trace amount of **2a** was obtained with **B**, and no corresponding product was observed with **C** (entries 6 and 7). The solvent was another important parameter for the success of the reaction. The use of the more polar solvents acetonitrile and methanol led to decomposition of the substrate (entries 8 and 9), whereas the less-polar solvent toluene inhibited the tandem reaction completely (entry 11). A comparable result was obtained in 1,2-dichloroethane (DCE; 45 % yield; entry 10). We therefore selected $CH_2Cl_2$ as the reaction solvent. Considering the possible role of the counter anion, we tested CuOAc combined with CuBr as the catalyst (entry 12), this improved the yield to 54 %. The yield was further increased to 64 % in the presence of a larger amount of Togni's reagent **A** (1.5 equiv; entry 13). Finally, after performing the reaction at different temperatures (entries 14 and 15), we found that catalytic amounts of CuOAc and CuBr, and $CH_2Cl_2$ at 28 °C gave the best results.

With the optimized conditions established, we explored the substrate scope of this reaction with various allylic alcohols **1b–l**. All of the substrates gave the desired β-trifluoromethyl ketone derivatives in moderate yields (Scheme 3). The reaction of a *para*-methyl-substituted arene also proceeded smoothly to afford the desired product **2b** in 61 % yield. We then tested substrates with a halogen substituent at the *para* position of the phenyl moiety. Interestingly, *p*-fluoro substituents did not affect the reaction efficiency, providing the corresponding product **2c** in 64 %




***Scheme 3.*** Scope of the trifluoromethylation/semipinacol rearrangement. Reaction conditions: Togni's reagent **A** (0.15 mmol) was dissolved in $CH_2Cl_2$ (1.0 mL) followed by the addition of the catalysts, CuOAc (0.015 mmol) and CuBr (0.015 mmol). After 5–10 min, **1a–l** (0.1 mmol) in $CH_2Cl_2$ (0.5 mL) was added. Yields shown are of isolated products. [a] The reaction proceeded with CuBr (0.03 mmol). [b] The reaction proceeded at 20 °C. [c] The reaction proceeded with CuOAc (0.03 mmol). [d] Under the standard conditions; $BF_3$·THF was then added after the allylic alcohols were no longer visible by TLC.

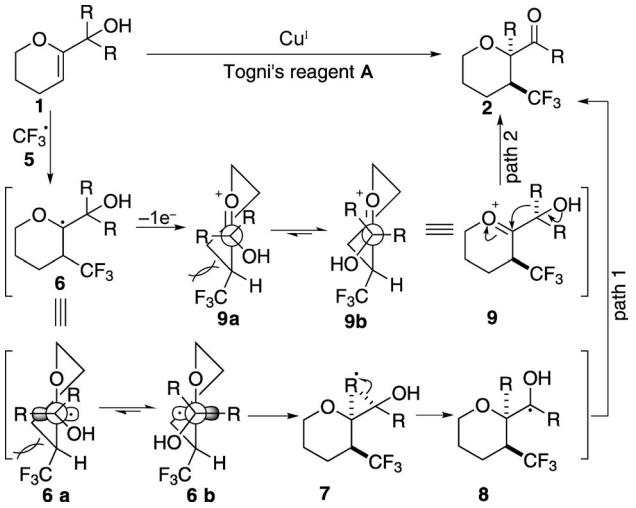
yield. However, the substrate with a 4-chlorophenyl group gave the corresponding product **2d** in relatively low yield (48%). In contrast, with model substrate **1a**, multiple substituents on the phenyl group significantly decreased the yield (**2e**, 35% yield). We next examined some substrates to explore the migration priority of the migrating groups ($R^1$ vs $R^2$). To our surprise, when unsymmetrical diaryl allylic alcohol **1f** was tested, the more electron-deficient 4-nitrophenyl group migrated to give product **2f** in 40% yield. This result indicates the possibility of the involvement of $CF_3$ radical species in this reaction (neophyl rearrangement).[19] For substrates with aryl and alkyl substituents (**1g–i**), as observed in general semipinacol rearrangements, the products **2g**, **2h**, and **2i**, with exclusive migration of the electron-richer aryl group were obtained in 63%, 65%, and 63% yields, respectively. The relative configuration of **2g** was unambiguously assigned by X-ray crystallography.[20] Notably, the reaction with substrate **1j**, which bears a cyclobutanol group, was also successful, giving the desired ring-expansion product **2j** in 70% yield. To further explore applications of the reaction, substrates with unactivated double bonds were also examined. The cyclic substrate **1k** afforded the corresponding product **2k** in 36% yield. It should be noted that substrates **1l** and **1m** were exclusively converted into the 3-trifluoromethyl-1,2-epoxides **3l** and **3m** under the standard conditions, which could subsequently undergo epoxide rearrangement in the presence of $BF_3$·THF to give the desired β-trifluoromethyl ketones **2l′** and **2m′** in 63% and 60% yields, respectively, in two steps.[21] Similarly, during the reaction of the acyclic substrate **1n**, 3-trifluoromethyl-1,2-epoxide **3n** was obtained in 61% yield, together with the desired product **2n** (20% yield). Furthermore, **3n** underwent semipinacol rearrangement (path A rather than path B, which would result in the formation of **2n**) in the presence of $BF_3$·$Et_2O$, and the α-trifluoromethyl ketone **4n** was obtained in 90% yield (Scheme 4). Finally, unsymmetrical acyclic allylic alcohol **1o** was also tested. Product **2o**, with exclusive migration of the aryl group, was obtained in 66% yield.




***Scheme 4.*** Rearrangement of epoxide **3n**.

To gain further mechanistic insights into this trifluoromethylation/semipinacol rearrangement reaction, additional experiments were conducted. When the radical scavengers 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) and 2,6-di-*tert*-butyl-*para*-cresol (BHT) were subjected to the standard reaction conditions, the formation of TEMPO–$CF_3$ and BHT–$CF_3$ adducts could be detected by GC-MS. For the reaction of substrate **1a** with TEMPO, although the rearrangement was mostly inhibited, we could still observe the presence of TEMPO–$CF_3$ along with a small amount of the expected product, **2a**, through GC-MS analysis of the reaction mixture. However, the same reaction with BHT resulted in a complex mixture, and no product could be detected except for BHT–$CF_3$. Therefore, we speculated that a $CF_3$ radical might be involved in this tandem reaction, although we could not rule out the existence of a possible iodonium intermediate.[11b]

Based on the experimental results above and those previously reported,[10c,d] we propose the reaction mechanism depicted in Scheme 5. Initially, $CF_3$ radical **5**, generated from




***Scheme 5.*** Proposed reaction mechanism.

Togni's reagent **A** in the presence of copper(I), would react with allylic alcohol **1** to produce intermediate **6**. Next, there are two possible reaction routes. For path 1, intermediate **6** could undergo a sterically favored 1,2-migration to afford intermediate **8**, which would produce product **2** upon further single-electron-transfer (SET) oxidation. In path 2, further oxidation of radical intermediate **6** would give cation intermediate **9**, and subsequent 1,2-rearrangement through transition state **9b** would provide the final product **2**. It should be noted that, for substrates with two aromatic groups, we prefer path 1.

In conclusion, we have developed a novel copper-catalyzed trifluoromethylation/semipinacol rearrangement reaction of allylic alcohols. This tandem reaction is valuable, as a series of α-quaternary β-trifluoromethyl ketones with different substituents were readily obtained. This method enables the construction of both $C_{sp^3}$–$CF_3$ bonds and a quaternary carbon center. Further studies are underway to investigate the applications of these transformations.

## Experimental Section

CuBr (0.15 equiv), CuOAc (0.15 equiv), and Togni's reagent **A** (1.5 equiv) in $CH_2Cl_2$ were stirred under argon at room temperature for 5–10 min. A solution of allylic alcohol **1** in $CH_2Cl_2$ was then added

and the mixture was stirred at 28 °C. After the substrate completely disappeared (as observed by thin-layer chromatography), the reaction mixture was directly subjected to column chromatography on silica gel eluted with either pentane/EtOAc (120:1–60:1) or pentane/$CH_2Cl_2$ (10:1–1:1) to give the desired product.

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[1] a) T. Yamazaki, T. Taguchi, I. Ojima in *Fluorine in Medicinal Chemistry and Chemical Biology* (Ed.: I. Ojima), Wiley-Blackwell, Chichester, **2009**, p. 3; b) M. Schlosser, *Angew. Chem.* **2006**, *118*, 5558; *Angew. Chem. Int. Ed.* **2006**, *45*, 5432; c) K. Müller, C. Faeh, F. Diederich, *Science* **2007**, *317*, 1881; d) K. William, W. K. Hagmann, *J. Med. Chem.* **2008**, *51*, 4359; e) S. Purser, P. R. Moore, S. Swallow, V. Gouverneur, *Chem. Soc. Rev.* **2008**, *37*, 320; f) K. L. Kirk, *Org. Process Res. Dev.* **2008**, *12*, 305.

[2] For selected reviews, see: a) T. Umemoto, *Chem. Rev.* **1996**, *96*, 1757; b) G. K. S. Prakash, A. K. Yudin, *Chem. Rev.* **1997**, *97*, 757; c) M. Shimizu, T. Hiyama, *Angew. Chem.* **2005**, *117*, 218; *Angew. Chem. Int. Ed.* **2005**, *44*, 214; d) J.-A. Ma, D. Cahard, *Chem. Rev.* **2008**, *108*, PR1; e) T. Furuya, A. S. Kamlet, T. Ritter, *Nature* **2011**, *473*, 470; f) O. A. Tomashenko, V. V. Grushin, *Chem. Rev.* **2011**, *111*, 4475; g) X.-F. Wu, H. Neumann, M. Beller, *Chem. Asian J.* **2012**, *7*, 1744; h) Y. Ye, M. S. Sanford, *Synlett* **2012**, 2005; i) T. Besset, C. Schneider, D. Cahard, *Angew. Chem.* **2012**, *124*, 5134; *Angew. Chem. Int. Ed.* **2012**, *51*, 5048; j) A. Studer, *Angew. Chem.* **2012**, *124*, 9082; *Angew. Chem. Int. Ed.* **2012**, *51*, 8950.

[3] For selected recent examples, see: a) J. Xu, B. Xiao, C.-Q. Xie, D.-F. Luo, L. Liu, Y. Fu, *Angew. Chem.* **2012**, *124*, 12719; *Angew. Chem. Int. Ed.* **2012**, *51*, 12551; b) S. P. Fritz, T. H. West, E. M. McGarrigle, V. K. Aggarwal, *Org. Lett.* **2012**, *14*, 6370; c) Y. Miyake, S. Ota, Y. Nishibayashi, *Chem. Eur. J.* **2012**, *18*, 13255; d) A. T. Parsons, T. D. Senecal, S. L. Buchwald, *Angew. Chem.* **2012**, *124*, 3001; *Angew. Chem. Int. Ed.* **2012**, *51*, 2947; e) Z. He, T. Luo, M. Hu, Y. Cao, J. Hu, *Angew. Chem.* **2012**, *124*, 4010; *Angew. Chem. Int. Ed.* **2012**, *51*, 3944.

[4] For selected recent examples, see: a) I. Kieltsch, P. Eisenberger, A. Togni, *Angew. Chem.* **2007**, *119*, 768; *Angew. Chem. Int. Ed.* **2007**, *46*, 754; b) D. A. Nagib, M. E. Scott, D. W. C. MacMillan, *J. Am. Chem. Soc.* **2009**, *131*, 10875; c) A. E. Allen, D. W. C. MacMillan, *J. Am. Chem. Soc.* **2010**, *132*, 4986; d) P. V. Pham, D. A. Nagib, D. W. C. Macmillan, *Angew. Chem.* **2011**, *123*, 6243; *Angew. Chem. Int. Ed.* **2011**, *50*, 6119; e) B. Morandi, E. M. Carreira, *Angew. Chem.* **2011**, *123*, 9251; *Angew. Chem. Int. Ed.* **2011**, *50*, 9085; f) A. T. Herrmann, L. L. Smith, A. Zakarian, *J. Am. Chem. Soc.* **2012**, *134*, 6976; g) Q.-H. Deng, H. Wadepohl, L. H. Gade, *J. Am. Chem. Soc.* **2012**, *134*, 10769; h) M. Hu, C. Ni, J. Hu, *J. Am. Chem. Soc.* **2012**, *134*, 15257; i) P. Novák, A. Lishchynskyi, V. V. Grushin, *J. Am. Chem. Soc.* **2012**, *134*, 16167.

[5] For selected recent examples, see: a) M. S. Wiehn, E. V. Vinogradova, A. Togni, *J. Fluorine Chem.* **2010**, *131*, 951; b) X. Wang, L. Truesdale, J.-Q. Yu, *J. Am. Chem. Soc.* **2010**, *132*, 3648; c) D. A. Nagib, D. W. C. MacMillan, *Nature* **2011**, *480*, 224; d) Y. Ye, S. H. Lee, M. S. Sanford, *Org. Lett.* **2011**, *13*, 5464; e) R. N. Loy, M. S. Sanford, *Org. Lett.* **2011**, *13*, 2548; f) X. Mu, S. Chen, X. Zhen, G. Liu, *Chem. Eur. J.* **2011**, *17*, 6039; g) Y. Ji, T. BrueckI, R. D. Baxter, Y. Fujiwara, I. B. Seiple, S. Su, D. G. Blackmond, P. S. Baran, *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 14411; h) A. Hafner, S. Bräse, *Angew. Chem.* **2012**, *124*, 3773; *Angew. Chem. Int. Ed.* **2012**, *51*, 3713; i) X.-G. Zhang, H.-X. Dai, M. Wasa, J.-Q. Yu, *J. Am. Chem. Soc.* **2012**, *134*, 11948; j) L. Chu, F.-L. Qing, *J. Am. Chem. Soc.* **2012**, *134*, 1298; k) E. Mejía, A. Togni, *ACS Catal.* **2012**, *2*, 521; l) Y. Fujiwara, J. A. Dixon, F. O'Hara, E. D. Funder, D. D. Dixon, R. A. Rodriguez, R. D. Baxter, B. Herlé, N. Sach, M. R. Collins, Y. Ishihara, P. S. Baran, *Nature* **2012**, *492*, 95; m) L.-S. Zhang, K. Chen, G. Chen, B.-J. Li, S. Luo, Q.-Y. Guo, J.-B. Wei, Z.-J. Shi, *Org. Lett.* **2013**, *15*, 10.

[6] a) M. Oishi, H. Kondo, H. Amii, *Chem. Commun.* **2009**, 1909; b) E. J. Cho, T. D. Senecal, T. Kinzel, Y. Zhang, D. A. Watson, S. L. Buchwald, *Science* **2010**, *328*, 1679; c) H. Morimoto, T. Tsubogo, N. D. Litvinas, J. F. Hartwig, *Angew. Chem.* **2011**, *123*, 3877; *Angew. Chem. Int. Ed.* **2011**, *50*, 3793; d) T. Knauber, F. Arikan, G.-V. Röschenthaler, L. Gooßn, *Chem. Eur. J.* **2011**, *17*, 2689; e) C.-P. Zhang, Z.-L. Wang, Q.-Y. Chen, C.-T. Zhang, Y.-C. Gu, J.-C. Xiao, *Angew. Chem.* **2011**, *123*, 1936; *Angew. Chem. Int. Ed.* **2011**, *50*, 1896; f) A. Zanardi, M. A. Novikov, E. Martin, J. Benet-Buchholz, V. V. Grushin, *J. Am. Chem. Soc.* **2011**, *133*, 20901; g) O. A. Tomashenko, E. C. Escudero-Adán, M. M. Belmonte, V. V. Grushin, *Angew. Chem.* **2011**, *123*, 7797; *Angew. Chem. Int. Ed.* **2011**, *50*, 7655; h) M. Döbele, M. S. Wiehn, S. Bräse, *Angew. Chem.* **2011**, *123*, 11737; *Angew. Chem. Int. Ed.* **2011**, *50*, 11533; i) I. Popov, S. Lindeman, O. Daugulis, *J. Am. Chem. Soc.* **2011**, *133*, 9286; j) B. S. Samant, G. W. Kabalka, *Chem. Commun.* **2011**, *47*, 7236.

[7] a) L. Chu, F.-L. Qing, *Org. Lett.* **2010**, *12*, 5060; b) J. Xu, D.-F. Luo, B. Xiao, Z.-J. Liu, T.-J. Gong, Y. Fu, L. Liu, *Chem. Commun.* **2011**, *47*, 4300; c) T. Liu, Q. Shen, *Org. Lett.* **2011**, *13*, 2342; d) T. D. Senecal, A. T. Parsons, S. L. Buchwald, *J. Org. Chem.* **2011**, *76*, 1174; e) T. Liu, X. Shao, Y. Wu, Q. Shen, *Angew. Chem.* **2012**, *124*, 555; *Angew. Chem. Int. Ed.* **2012**, *51*, 540; f) N. D. Litvinas, P. S. Fier, J. F. Hartwig, *Angew. Chem.* **2012**, *124*, 551; *Angew. Chem. Int. Ed.* **2012**, *51*, 536; g) P. Novák, A. Lishchynskyi, V. V. Grushin, *Angew. Chem.* **2012**, *124*, 7887; *Angew. Chem. Int. Ed.* **2012**, *51*, 7767; h) Y. Ye, M. S. Sanford, *J. Am. Chem. Soc.* **2012**, *134*, 9034; i) Q. Qi, Q. Shen, L. Lu, *J. Am. Chem. Soc.* **2012**, *134*, 6548; j) Y. Li, L. Wu, H. Neumann, M. Beller, *Chem. Commun.* **2013**, *49*, 2628.

[8] a) H. Kawai, Y. Sugita, E. Tokunaga, H. Sato, M. Shiro, N. Shibata, *Chem. Commun.* **2012**, *48*, 3632; b) N. Shibata, T. Nishimine, N. Shibata, E. Tokunaga, K. Kawada, T. Kagawa, A. E. Sorochinsky, V. A. Soloshonok, *Chem. Commun.* **2012**, *48*, 4124.

[9] a) D. V. Sevenard, V. Y. Sosnovskikh, A. A. Kolomeitsev, M. H. Königsmann, G.-V. Röschenthaler, *Tetrahedron Lett.* **2003**, *44*, 7623; b) V. Y. Sosnovskikh, B. I. Usachev, D. V. Sevenard, G.-V. Röschenthaler, *J. Org. Chem.* **2003**, *68*, 7747; c) V. Y. Sosnovskikh, B. I. Usachev, D. V. Sevenard, G.-V. Röschenthaler, *Tetrahedron Lett.* **2003**, *44*, 2097; d) A. D. Dilman, V. V. Levin, P. A. Belyakov, M. I. Stuchkova, V. A. Tartakovsky, *Tetrahedron Lett.* **2008**, *49*, 4352; e) A. A. Zemtsov, V. V. Levin, A. D. Dilman, M. I. Stuchkova, P. A. Belyakov, V. A. Tartakovsky, *Tetrahedron Lett.* **2009**, *50*, 2998; f) A. A. Zemtsov, V. V. Levin, A. D. Dilman, M. I. Stuchkova, P. A. Belyakov, V. A. Tartakovsky, J. Hu, *Eur. J. Org. Chem.* **2010**, 6779; g) R. Shimizu, H. Egami, Y. Hamashima, M. Sodeoka, *Angew. Chem.* **2012**, *124*, 4655; *Angew. Chem. Int. Ed.* **2012**, *51*, 4577; h) S. Mizuta, O. Galicia-López, K. M. Engle, S. Verhoog, K. Wheelhouse, G. Rassias, V. Gouverneur, *Chem. Eur. J.* **2012**, *18*, 8583; i) N. Iqbal, S. Choi, E. Kim, E. J. Cho, *J. Org. Chem.* **2012**, *77*, 11383; j) Y. Yasu, T. Koike, M. Akita, *Angew. Chem.* **2012**, *124*, 9705; *Angew. Chem. Int. Ed.* **2012**, *51*, 9567.

[10] a) A. T. Parsons, S. L. Buchwald, *Angew. Chem.* **2011**, *123*, 9286; *Angew. Chem. Int. Ed.* **2011**, *50*, 9120; b) J. Xu, Y. Fu, D.-F. Luo, Y.-Y. Jiang, B. Xiao, Z.-J. Liu, T.-J. Gong, L. Liu, *J. Am. Chem. Soc.* **2011**, *133*, 15300; c) X. Wang, Y. Ye, S. Zhang, J. Feng, Y. Xu, Y. Zhang, J. Wang, *J. Am. Chem. Soc.* **2011**, *133*, 16410; d) L. Chu, F.-L. Qing, *Org. Lett.* **2012**, *14*, 2106; e) X. Wu, L. Chu, F.-L. Qing, *Angew. Chem.* **2013**, *125*, 2254; *Angew. Chem. Int. Ed.* **2013**, *52*, 2198; f) S. Mizuta, S. Verhoog, K. M. Engle, T.

  

Khotavivattana, M. O'Duill, K. Wheelhouse, G. Rassias, M. Médebielle, V. Gouverneur, *J. Am. Chem. Soc.* **2013**, *135*, 2505.
[11] a) P. G. Janson, I. N. Ghoneim, O. Ilchenko, K. J. Szabó, *Org. Lett.* **2012**, *14*, 2882; b) C. Feng, T.-P. Loh, *Chem. Sci.* **2012**, *3*, 3458; c) R. Zhu, S. L. Buchwald, *J. Am. Chem. Soc.* **2012**, *134*, 12462; d) H. Egami, R. Shimizu, M. Sodeoka, *Tetrahedron Lett.* **2012**, *53*, 5503.
[12] a) X. Mu, T. Wu, H. Wang, Y. Guo, G. Liu, *J. Am. Chem. Soc.* **2012**, *134*, 878; b) H. Egami, R. Shimizu, S. Kawamura, M. Sodeoka, *Angew. Chem.* **2013**, *125*, 4092; *Angew. Chem. Int. Ed.* **2013**, *52*, 4000; c) During the revision of this manuscript, related research on copper-catalyzed trifluoromethylation-initiated radical 1,2-aryl migration in α,α-diaryl allylic alcohols was published: X. Liu, F. Xiong, X. Huang, L. Xu, P. Li, X. Wu, *Angew. Chem.* **2013**, *125*, 7100; *Angew. Chem. Int. Ed.* **2013**, *52*, 6962.
[13] a) L. A. Paquette, D. R. Owen, R. T. Bibart, C. K. Seekamp, A. L. Kahane, J. C. Lanter, M. A. Corral, *J. Org. Chem.* **2001**, *66*, 2828; b) P. B. Hurley, G. R. Dake, *J. Org. Chem.* **2008**, *73*, 4131; c) S. A. Snyder, Z.-Y. Tang, R. Gupta, *J. Am. Chem. Soc.* **2009**, *131*, 5744; d) Z.-L. Song, C.-A. Fan, Y.-Q. Tu, *Chem. Rev.* **2011**, *111*, 7523.
[14] a) B. Rickborn in *Comprehensive Organic Synthesis*, *Vol. 3* (Eds: B. M. Trost, I. Fleming), Pergamon, Oxford, **1991**, p. 721; b) L. E. Overman, *Acc. Chem. Res.* **1992**, *25*, 352; c) T. J. Snape, *Chem. Soc. Rev.* **2007**, *36*, 1823; d) B. Wang, Y.-Q. Tu, *Acc. Chem. Res.* **2011**, *44*, 1207.
[15] For selected examples of asymmetric semipinacol rearrangements, see: a) B. M. Trost, J. Xie, *J. Am. Chem. Soc.* **2006**, *128*, 6044; b) Q.-W. Zhang, C.-A. Fan, H.-J. Zhang, Y.-Q. Tu, Y.-M. Zhao, P. Gu, Z.-M. Chen, *Angew. Chem.* **2009**, *121*, 8724; *Angew. Chem. Int. Ed.* **2009**, *48*, 8572; c) F. Kleinbeck, F. D. Toste, *J. Am. Chem. Soc.* **2009**, *131*, 9178; d) E. Zhang, C.-A. Fan, Y.-Q. Tu, F.-M. Zhang, Y.-L. Song, *J. Am. Chem. Soc.* **2009**, *131*, 14626; e) Z.-M. Chen, Q.-W. Zhang, Z.-H. Chen, H. Li, Y.-Q. Tu, F.-M. Zhang, J.-M. Tian, *J. Am. Chem. Soc.* **2011**, *133*, 8818; f) C. Müller, H. M. Wilking, A. Rühlmann, B. Wibbeling, U. Hennecke, *Synlett* **2011**, 2043; g) Z. Chai, T. J. Rainey, *J. Am. Chem. Soc.* **2012**, *134*, 3615; h) Z.-M. Chen, B.-M. Yang, Z.-H. Chen, Q.-W. Zhang, M. Wang, Y.-Q. Tu, *Chem. Eur. J.* **2012**, *18*, 12950; i) T. Hashimoto, S. Isobe, C. K. A. Callens, K. Maruoka, *Tetrahedron* **2012**, *68*, 7630.
[16] a) I. L. Lysenko, H.-S. Oh, J. K. Cha, *J. Org. Chem.* **2007**, *72*, 7903; b) A. M. Meyer, C. E. Katz, S.-W. Li, D. V. Velde, J. Aubé, *Org. Lett.* **2010**, *12*, 1244; c) R. J. Phipps, L. McMurray, S. Ritter, H. A. Duong, M. J. Gaunt, *J. Am. Chem. Soc.* **2012**, *134*, 10773.
[17] P. Eisenberger, S. Gischig, A. Togni, *Chem. Eur. J.* **2006**, *12*, 2579.
[18] T. Umemoto, S. Ishihara, *J. Am. Chem. Soc.* **1993**, *115*, 2156.
[19] C. S. Aureliano Antunes, M. Bietti, G. Ercolani, O. Lanzalunga, M. Salamone, *J. Org. Chem.* **2005**, *70*, 3884.
[20] CCDC 919387 (**2g**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.
[21] For details, see the Supporting Information.

  