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Graphical Abstract

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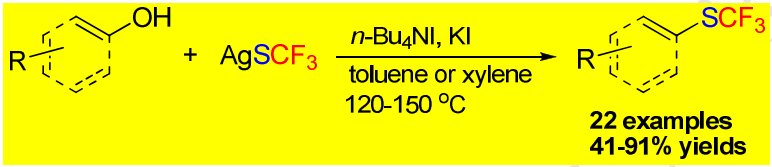

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Synthesis of vinyl and electron-deficient aryl trifluoromethyl sulfides via Csp^2–OH bond activation with $AgSCF_3$ and *n*-Bu_4NI/KI

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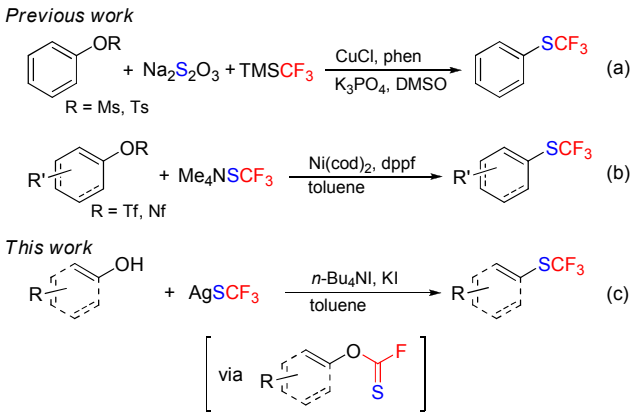
ABSTRACT

Direct dehydroxytrifluoromethylthiolation of enols and electron-deficient phenols with $AgSCF_3$ in the presence of *n*-Bu_4NI and KI is reported, affording a series of vinyl and aryl trifluoromethyl sulfides in moderate to excellent yields. This work represents a rare example of direct functionalization of Csp^2–OH bonds.

1. Introduction

The introduction of fluorine atom and fluorine-containing groups into organic compounds can significantly alter their chemical, physical, and biological properties.[1] For example, the trifluoromethylthio group (SCF_3) has been incorporated into many pharmaceuticals and agrochemicals such as Fipronil,[2a] Tiflorex,[2b] Toltrazuril,[2c] and Cefazaflur,[2d] due to its extremely high lipophilicity and specific electronic properties.[3] Over the past several years, the development of new trifluoromethylthiolating reagents and trifluoromethylthiolation reactions have witnessed significant progress.[4] Especially, numerous efforts have been devoted to the synthesis of aryl and vinyl trifluoromethyl sulfides. A variety of transition-metal-mediated/catalyzed trifluoromethylthiolation reactions have been developed for the direct conversion of Csp^2–X (X = H,[5] $B(OR)_2$,[6] CO_2H,[7] diazonium salt,[8] halide[9]) bonds to Csp^2–SCF_3 bonds. However, the direct formation of Csp^2–SCF_3 bonds from Csp^2–OR bonds remains less explored. To date, only two studies have been reported, which focused on the coupling of aryl and/or vinyl sulfonates for the preparation of corresponding trifluoromethyl sulfides. In 2014, Zhong and Liu exploited a copper-catalyzed trifluoromethylthiolation of aryl sulfonates using $Na_2S_2O_3$ and $TMSCF_3$ as the SCF_3 source (Scheme 1a).[10a] Recently, Schoenebeck and co-workers disclosed an efficient nickel-catalyzed trifluoromethylthiolation of aryl, vinyl triflates and nonaflates with Me_4NSCF_3 (Scheme 1b).[10b] To the best of our knowledge, the direct trifluoromethylthiolation of Csp^2–OH bonds has never been reported.



Scheme 1 Direct conversion of Csp^2–O bonds to Csp^2–SCF_3 bonds.

In 2015, our group developed a direct dehydroxytrifluoromethylthiolation of alcohols with $AgSCF_3$ and

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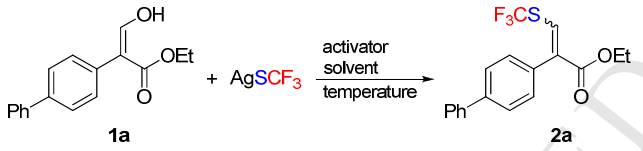
n-Bu_4NI on the basis of the equilibrium between trifluoromethanethiolate (SCF_3^-) with carbonothioic difluoride ($S=CF_2$) and fluoride anion (F^-).[11a] This work not only opened up new opportunities for direct trifluoromethylthiolation of Csp^3−OH bonds,[11] but also stimulated wide interest of the $S=CF_2$ chemistry.[12] Encouraged by this work and continuing with our research on trifluoromethylthiolation reactions,[11a,13] herein we report the first trifluoromethylthiolation of Csp^2−OH bonds (Scheme 1c). This protocol allows a convenient synthesis of various vinyl and aryl trifluoromethyl sulfides from simple enols and electron-deficient phenols.

2. Results and discussion

Enols and phenols are fundamental structural moieties in organic chemistry. Consequently, the functionalization of the enols and phenols has received wide research interest. Normally, these compounds are first converted to the corresponding sulfonates or carbonates for further transformations. However, the direct Csp^2−OH bond functionalization were less explored. Recently, Ritter[14] and Sanford[15] respectively disclosed deoxyfluorination of phenols with PhenoFluor or SO_2F_2/NMe_4F. Inspired by these work, we hypothesized that direct trifluoromethylthiolation of Csp^2−OH bonds should be feasible by adopting our dehydroxytrifluoromethylthiolation strategy.[11a] We envisioned that the activation of $AgSCF_3$ with *n*-Bu_4NI would result in the formation of active source of $[SCF_3]^-$,[16] which decomposed to generate carbonothioic difluoride ($S=CF_2$). Then, the reaction of Csp^2−OH with $S=CF_2$ formed Csp^2−OC(S)F intermediates, which could be substituted by $[SCF_3]^-$ to afford the final product (Scheme 1c).

Table 1. Optimization of reaction conditions.[a]

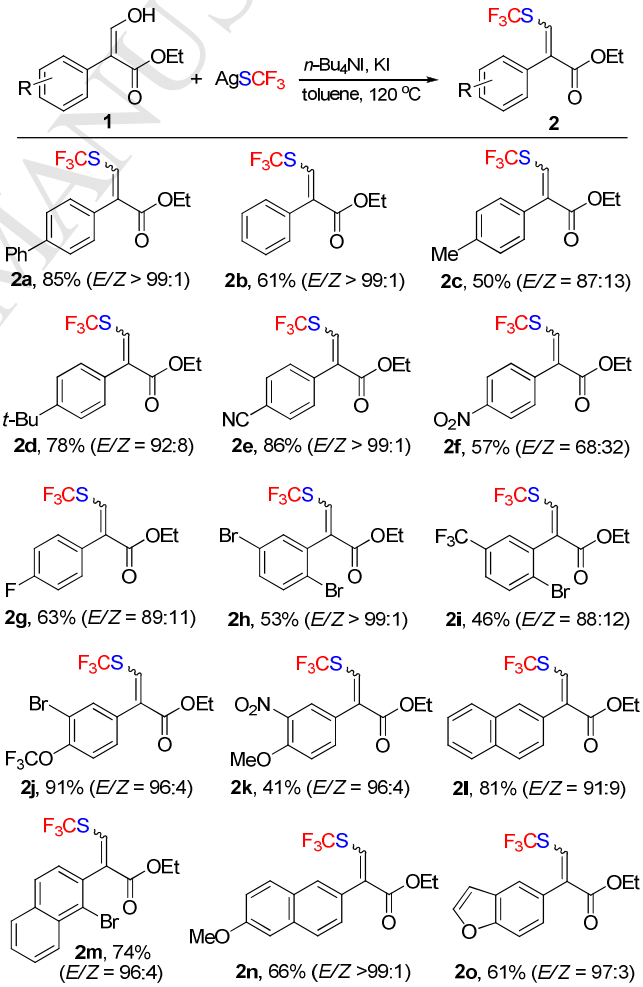


1a **2a**

Entry	Activator	Solvent	Temperature	Yield (%)[b]
1	*n*-Bu_4NI	toluene	80 °C	0
2	*n*-Bu_4NI + KI	toluene	80 °C	54
3	*n*-Bu_4NBr + KI	toluene	80 °C	17
4	*n*-Bu_4NI + KBr	toluene	80 °C	8
5	*n*-Bu_4NI + KI	DCE	80 °C	12
6	*n*-Bu_4NI + KI	CH_3CN	80 °C	30
7	*n*-Bu_4NI + KI	DMF	80 °C	trace
8	*n*-Bu_4NI + KI	toluene	100 °C	68
9	*n*-Bu_4NI + KI	toluene	120 °C	89
10	*n*-Bu_4NI + KI	toluene	140 °C	72
11[c]	*n*-Bu_4NI + KI	toluene	120 °C	43
12	KI	toluene	120 °C	0
13[d]	*n*-Bu_4NI + KI	toluene	120 °C	0
14[e]	—	toluene	120 °C	0
15[e]	KI	toluene	120 °C	trace

[a]*Reaction conditions*: **1a** (0.2 mmol), $AgSCF_3$ (0.6 mmol), *n*-Bu_4NI (1.8 mmol), KI (1.2 mmol), solvent (2.0 mL), under N_2, temperature, 5 h.
[b]Yields determined by ^{19}F NMR spectroscopy using trifluoromethylbenzene as an internal standard.
[c]$AgSCF_3$ (0.4 mmol), *n*-Bu_4NI (1.2 mmol), KI (0.8 mmol).
[d]$CuSCF_3$ (0.6 mmol).
[e]Me_4NSCF_3 (0.6 mmol).

To test our hypothesis, (*Z*)-ethyl 2-(biphenyl-4-yl)-3-hydroxyacrylate (**1a**) was chosen as the model substrate for the dehydroxytrifluoromethylthiolation (Table 1). When **1a** was treated with $AgSCF_3$ (3.0 equiv) and *n*-Bu_4NI (9.0 equiv) in toluene under the optimal reaction conditions of dehydroxytrifluoromethylthiolation of alcohols,[11a] none of the trifluoromethylthiolated product was observed (entry 1). Apparently, the dehydroxytrifluoromethylthiolation of Csp^2−OH bonds is more challenging than that of Csp^3−OH bonds. To our delight, the employment of both of *n*-Bu_4NI and KI as the activator afforded the desired product **2a** in 54% yield (entry 2). Switching the activator from *n*-Bu_4NI to *n*-Bu_4NBr (entry 3) or from KI to KBr (entry 4) resulted in lower yields. When this reaction was performed in other solvents including DCE, CH_3CN, and DMF, **2a** was formed in lower yields (entries 5-7). The screening of different temperature revealed that 120 °C was optimal, delivering **2a** in 89% yield (entries 8-10). Notably, a dramatic drop in the yield was observed when decreasing the amounts of $AgSCF_3$, *n*-Bu_4NI, and KI (entry 11). Furthermore, none of the desired product **2a** was detected upon using KI as the activator (entry 12). Finally, other SCF_3 sources including $CuSCF_3$ and Me_4NSCF_3 were investigated (entries 13-15). However, both of them were sluggish to this reaction.

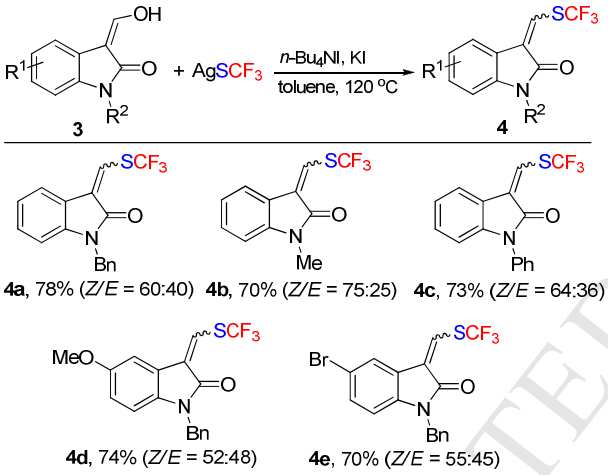


Scheme 2 Substrate scope of dehydroxytrifluoromethylthiolation of enols. [a]*Reaction conditions*: **1** (0.2 mmol), $AgSCF_3$ (0.6 mmol), *n*-Bu_4NI (1.8 mmol), KI (1.2 mmol), toluene (2.0 mL), under N_2, 120 °C, 5 h. Yields are those of isolated products. *E*/*Z* ratios were determined by ^{19}F NMR spectroscopy of the crude reaction mixture.

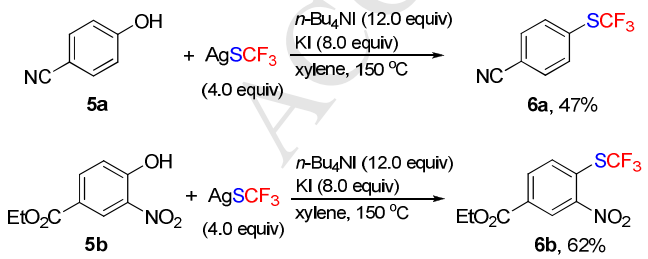
With the optimized conditions (Table 1, entry 9) in hand, we then investigated the substrate scope of

dehydroxytrifluoromethylthiolation of enols. As shown in Scheme 2, a series of enols **1a-k** underwent this transformation smoothly, furnishing the trifluoromethylthiolated alkenes **2a-k** in high yields and excellent *E/Z* selectivities. The configuration of product **2** was determined by comparison of the ^{19}F NMR spectroscopy with that of the literature data,[17] suggesting an *E* configuration of the major isomer. This reaction system was compatible with electronically diverse functionalities, including alkyl (**1c**,**d**), alkoxy (**1k**), aryl (**1a**), cyano (**1e**), nitro (**1f**,**k**), fluoro (**1g**), bromo (**1h-j**), trifluoromethyl (**1i**), and trifluoromethoxy (**1j**) substituents. Additionally, naphthyl-substituted enols **1l-n** were also applicable substrates, the transformation of which provided the corresponding products in moderate to high yields. In the case of substrate (**1o**) containing benzofuran heterocycle, the desired product was obtained in 61% yield and excellent *E/Z* selectivity.

This dehydroxytrifluoromethylthiolation protocol could also be extended to other types of enols. For example, enols **3a-e** derived from oxindoles were successfully converted to the trifluoromethylthiolated products in high yields, albeit with low *Z/E* selectivities (Scheme 3). Considering the biological importance of oxindole scaffolds,[18] the resulting SCF_3-containing oxindole derivatives might be potentially useful in drug discovery.



Scheme 3 Substrate scope of dehydroxytrifluoromethylthiolation of enols derived from oxindoles. [a]*Reaction conditions*: **3** (0.2 mmol), $AgSCF_3$ (0.6 mmol), *n*-Bu_4NI (1.8 mmol), KI (1.2 mmol), toluene (2.0 mL), under N_2, 120 °C, 5 h. Yields are those of isolated products. *E*/*Z* ratios were determined by ^{19}F NMR spectroscopy of the crude reaction mixture.



Scheme 4 Dehydroxytrifluoromethylthiolation of electron-deficient phenols.

To further enlighten the synthetic utility of this method, we then turned our attention to the dehydroxytrifluoromethylthiolation of phenols. However, low yield was obtained when phenol **5a** was subjected to the standard reaction conditions (Table 1, entry 9). After slightly modification of the reaction conditions, including changing the solvent, increasing the amounts of reagents, and elevating the reaction temperature, the dehydroxytrifluoromethylthiolation of electron-deficient phenols **5a** and **5b** proceeded well, affording the corresponding trifluoromethyl sulfides **6a** and **6b** in moderate yields, respectively (Scheme 4). It was as noteworthy that electron-rich and -neutral phenols were not suitable substrates for this reaction.

In conclusion, we have developed an efficient method for the transforming of enols and electron-deficient phenols to the corresponding vinyl and aryl trifluoromethyl sulfides. The activation of $AgSCF_3$ with *n*-Bu_4NI and KI in toluene is the key to this Csp^2–OH bond transformation. A wide panel of functional groups was well tolerated under the reaction conditions, and the desired products were obtained in moderate to excellent yields. Further investigations of other dehydroxytrifluoromethylthiolation reactions are currently in progress in our laboratory.

3. Experimental section

3.1. General information

^{1}H and ^{19}F NMR ($CFCl_3$ as outside standard and low field is positive) spectra were recorded on a Bruker AM 400 spectrometer. ^{13}C NMR spectra were recorded on a Bruker AM 400 spectrometer. Chemical shifts (δ) were reported in ppm, and coupling consta nts (*J*) were in Hertz (Hz). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. High resolution mass spectra (HRMS) were performed using a GC/MS TOF high-resolution mass spectrometer equipped with a liquid chromatography system. Unless otherwise noted, all reagents were obtained commercially and used without further purification. The synthesis of enols **1a-o** and **3a-e** were reported in detail in supporting information.

3.2. General procedure for dehydroxytrifluoromethylthiolation of enols

A 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with $AgSCF_3$ (125.3 mg, 0.6 mmol), *n*-Bu_4NI (664.9 mg, 1.8 mmol), and KI (199.2 mg, 1.2 mmol). The tube was evacuated and backfilled with N_2 for three times. Then, enol (0.2 mmol) and toluene (2.0 mL) were added to the tube. The tube was placed into a preheated oil bath at 120 °C with vigorous stirring. After 5 h, the reaction mixture was cooled to room temperature and filtered through a plug of silica (eluted with EtOAc). The filtrate was concentrated, and the product was purified by column chromatography on silica gel to give the desired product.

*3.2.1. (E)-Ethyl 2-(biphenyl-4-yl)-3-(trifluoromethylthio)acrylate (**2a**)*

Yield 85% (58.8 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.80 (s, 1H), 7.61 (d, *J* = 8.6 Hz, 2H), 7.44 (d, *J* = 7.6 Hz, 2H), 7.36 (d, *J* = 7.3 Hz, 2H), 7.31-7.04 (m, 3H), 4.28 (q, *J* = 7.1 Hz, 2H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.04 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.1, 141.7, 140.4, 133.2, 132.4, 131.1 (q, *J* = 3.5 Hz), 129.3, 128.9 (q, *J* = 310.3 Hz), 127.6, 127.2, 127.1, 61.6, 14.2; IR (thin film) ν 2984, 1717, 1488, 1369, 1237, 1111, 1036, 908 cm^{-1}; MS (ESI): *m/z* 353 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{18}H_{16}F_3O_2S$ $[M+H]^+$: 353.0815; Found: 353.0818.

*3.2.2. (E)-Ethyl 2-phenyl-3-(trifluoromethylthio)acrylate (**2b**)*

Yield 61% (33.7 mg), red oil, eluent for column chromatography: hexane/EtOAc (60:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 (s, 1H), 7.45-7.35 (m, 3H), 7.25 (d, *J* = 8.0 Hz, 2H), 4.27 (q, *J* = 7.1 Hz, 2H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.09 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.1, 133.6, 133.5, 131.1 (q, *J* = 3.5 Hz), 130.4, 128.9 (q, *J* = 310.1 Hz), 128.5, 124.9, 61.6, 14.2; IR (thin film) ν 2984, 1713, 1494, 1369, 1238, 1112, 1041, 907 cm^{-1}; MS (ESI): *m/z* 277 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{12}H_{12}F_3O_2S$ $[M+H]^+$: 277.0505; Found: 277.0503.

*3.2.3. (E)-Ethyl 2-p-tolyl-3-(trifluoromethylthio)acrylate (**2c**)*

Yield 50% (29.2 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.76 (s, 1H), 7.18 (d, *J* = 7.7 Hz, 2H), 7.12 (d, *J* = 6.7 Hz, 2H), 4.29-4.23 (m, 2H), 2.37 (s, 3H), 1.44-1.39 (m, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.16 (s, 2.6F), -45.48 (s, 0.4F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.3, 138.9, 130.7 (q, *J* = 4.0 Hz), 130.5, 129.3, 128.8, 128.6 (q, *J* = 295.3 Hz), 124.4, 61.6, 21.4, 14.2; IR (thin film) ν 2985, 1716, 1511, 1369, 1237, 1112, 1039, 908 cm^{-1}; MS (ESI): *m/z* 291 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{13}H_{14}F_3O_2S$ $[M+H]^+$: 291.0661; Found: 291.0659.

*3.2.4. (E)-Ethyl 2-(4-tert-butylphenyl)-3-(trifluoromethylthio)acrylate (**2d**)*

Yield 78% (51.8 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.76 (s, 1H), 7.43 (d, *J* = 8.0 Hz, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 4.28 (q, *J* = 7.2 Hz, 2H), 1.34-1.31 (m, 12H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.19 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.3, 151.9, 133.5, 130.6 (q, *J* = 3.1 Hz), 130.4, 129.0 (q, *J* = 311.1 Hz), 128.6, 125.5, 61.6, 34.7, 31.2, 14.2; IR (thin film) ν 2966, 1717, 1508, 1368, 1237, 1112, 1040, 908 cm^{-1}; MS (ESI): *m/z* 333 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{13}H_{14}F_3O_2S$ $[M+H]^+$: 333.1131; Found: 333.1129.

*3.2.5. (E)-Ethyl 2-(4-cyanophenyl)-3-(trifluoromethylthio)acrylate (**2e**)*

Yield 86% (51.8 mg), red oil, eluent for column chromatography: hexane/CH_2Cl_2 (1:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (s, 1H), 7.69 (d, *J* = 8.4 Hz, 2H), 7.36 (d, *J* = 8.0 Hz, 2H), 4.25 (q, *J* = 7.1 Hz, 2H), 1.27 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.75 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.2, 138.1, 132.8 (q, *J* = 4.0 Hz), 132.3, 131.9, 129.9, 128.5 (q, *J* = 310.1 Hz), 118.3, 112.8, 62.0, 14.1; IR (thin film) ν 2985, 2232, 1714, 1369, 1240, 1108, 1037, 909 cm^{-1}; MS (ESI): *m/z* 302 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{13}H_{11}F_3NO_2S$ $[M+H]^+$: 302.0457; Found: 302.0454.

*3.2.6. (E)-Ethyl 2-(4-nitrophenyl)-3-(trifluoromethylthio)acrylate (**2f**)*

Yield 57% (36.6 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.29 (d, *J* = 8.8 Hz, 2H), 7.93 (s, 1H), 7.46 (d, *J* = 8.8 Hz, 2H), 4.30 (q, *J* = 7.2 Hz, 2H), 1.32 (t, *J* = 7.2 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.70 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.1, 147.9, 140.0, 133.1 (q, *J* = 4.0 Hz), 130.2, 128.5 (q, *J* = 311.1 Hz), 124.9, 123.8, 62.1, 14.2; IR (thin film) ν 2985, 1716, 1511, 1369, 1237, 1112, 1039, 908 cm^{-1}; MS (ESI): *m/z* 322 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{12}H_{11}F_3NO_4S$ $[M+H]^+$: 322.0355; Found: 322.0354.

*3.2.7. (E)-Ethyl 2-(4-fluorophenyl)-3-(trifluoromethylthio)acrylate (**2g**)*

Yield 63% (37.0 mg), red oil, eluent for column chromatography: hexane/EtOAc (30:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.79 (s, 1H), 7.30-7.25 (m, 2H), 7.17-7.13 (m, 2H), 4.30 (q, *J* = 7.1 Hz, 2H), 1.35 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.96 (s, 3F), -111.87 to -111.95 (m, 1F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.9, 162.8 (d, *J* = 249.5 Hz), 132.6, 131.6 (q, *J* = 3.0 Hz), 130.9, 130.8, 129.4, 128.8 (q, *J* = 310.1 Hz), 115.8, 115.6, 61.7, 14.2; IR (thin film) ν 2985, 1714, 1509, 1369, 1236, 1112, 1036, 907 cm^{-1}; MS (ESI): *m/z* 295 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{12}H_{11}F_4O_2S$ $[M+H]^+$: 295.0410; Found: 295.0408.

*3.2.8. (E)-Ethyl 2-(2,5-dibromophenyl)-3-(trifluoromethylthio)acrylate (**2h**)*

Yield 53% (46.0 mg), red oil, eluent for column chromatography: hexane/EtOAc (15:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.87 (s, 1H), 7.49 (d, *J* = 8.5 Hz, 1H), 7.37 (dd, *J* = 8.5, 2.4 Hz, 1H), 7.30 (d, *J* = 2.3 Hz, 1H), 4.23 (q, *J* = 7.1 Hz, 2H), 1.26 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.32 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 162.7, 136.4, 134.5, 131.6 (q, *J* = 4.0 Hz), 133.6, 133.3, 132.2, 128.6 (q, *J* = 310.1 Hz), 122.2, 121.3, 61.9, 14.1; IR (thin film) ν 2983, 1715, 1455, 1384, 1283, 1108, 1050, 907 cm^{-1}; MS (ESI): *m/z* 433 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{12}H_{10}Br_2F_3O_2S$ $[M+H]^+$: 432.8715; Found: 432.8713.

*3.2.9. (E)-Ethyl 2-(2-bromo-5-(trifluoromethyl)phenyl)-3-(trifluoromethylthio)acrylate (**2i**)*

Yield 46% (38.8 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.92 (s, 1H), 7.78 (d, *J* = 8.5 Hz, 1H), 7.53-7.47 (m, 1H), 7.43 (s, 1H), 4.33-4.25 (m, 2H), 1.26 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.31 (s, 3F), -62.75 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 162.6, 135.5, 133.9 (q, *J* = 3.6 Hz), 133.8, 132.3, 130.4 (q, *J* = 33.3 Hz), 128.8 (q, *J* = 310.0 Hz), 127.6, 127.5 (q, *J* = 3.7 Hz), 127.2 (q, *J* = 3.6 Hz), 125.9 (q, *J* = 225.6 Hz), 62.0, 14.1; IR (thin film) ν 2888, 1696, 1571, 1429, 1203, 1070, 906, 777 cm^{-1}; MS (ESI): *m/z* 423 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{13}H_{10}BrF_6O_2S$ $[M+H]^+$: 422.9484; Found: 422.9482.

*3.2.10. (E)-Ethyl 2-(3-bromo-4-(trifluoromethoxy)phenyl)-3-(trifluoromethylthio)acrylate (**2j**)*

Yield 91% (80.2 mg), red oil, eluent for column chromatography: hexane/EtOAc (10:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85 (s, 1H), 7.54 (d, *J* = 2.1 Hz, 1H), 7.34 (dd, *J* = 8.5, 1.4 Hz, 1H), 7.25-7.20 (m, 1H), 4.26 (q, *J* = 7.1 Hz, 2H), 1.30 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.86 (s, 2.93F), -45.38 (s, 0.07F), -57.54 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.3, 146.7, 134.7, 132.8 (q, *J* = 4.0 Hz), 131.1, 129.5, 128.6 (q, *J* = 310.1 Hz), 121.9, 120.8 (q, *J* = 260.1 Hz), 116.2, 61.9, 14.1; MS (ESI): *m/z* 439 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{13}H_{10}BrF_6O_3S$ $[M+H]^+$: 438.9433; Found: 438.9435.

*3.2.11. (E)-Ethyl 2-(4-methoxy-3-nitrophenyl)-3-(trifluoromethylthio)acrylate (**2k**)*

Yield 41% (28.8 mg), red oil, eluent for column chromatography: hexane/EtOAc (6:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (d, *J* = 9.6 Hz, 1H), 7.77 (d, *J* = 2.1 Hz, 1H), 7.43 (dd, *J* = 8.7, 2.2 Hz, 1H), 7.11 (d, *J* = 7.8 Hz, 1H), 4.29 (q, *J* = 7.2 Hz, 2H), 3.97 (s, 3H), 1.33 (t, *J* = 7.2 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.73 (s, 2.86F), -45.29 (s, 0.14F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.5, 153.2, 139.4, 134.9, 132.5 (q, *J* = 3.0 Hz), 130.9, 128.6 (q, *J* = 310.1 Hz), 126.7, 125.6, 113.6, 62.0, 56.7, 14.2; IR (thin film) ν 2986, 1716, 1533, 1352, 1240, 1110, 1017, 804 cm^{-1}; MS (ESI): *m/z* 352 $[M+H]^+$; HRMS (ESI-TOF):

m/z Calculated for $C_{13}H_{13}F_3NO_5S$ $[M+H]^+$: 352.0641; Found: 352.0640.

*3.2.12. (E)-Ethyl 2-(naphthalen-2-yl)-3-(trifluoromethylthio)acrylate (**2l**)*

Yield 81% (52.8 mg), red oil, eluent for column chromatography: hexane/EtOAc (50:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91-7.85 (m, 4H), 7.72 (s, 1H), 7.52 (t, *J* = 3.6 Hz, 2H), 7.36 (d, *J* = 8.8, 1H), 4.31 (q, *J* = 7.2 Hz, 2H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.04 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.1, 133.2, 132.9, 131.6 (q, *J* = 4.0 Hz), 131.1, 128.9 (q, *J* = 310.1 Hz), 128.5, 128.3, 128.2, 127.8, 126.9, 126.5, 126.3, 61.7, 14.2; IR (thin film) ν 2983, 1715, 1369, 1235, 1110, 1040, 906 cm^{-1}; MS (ESI): *m/z* 327 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{16}H_{14}F_3O_2S$ $[M+H]^+$: 327.0661; Found: 327.0658.

*3.2.13. (E)-Ethyl 2-(1-bromonaphthalen-2-yl)-3-(trifluoromethylthio)acrylate (**2m**)*

Yield 74% (60.0 mg), red oil, eluent for column chromatography: hexane/EtOAc (20:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.37 (d, *J* = 8.4 Hz, 1H), 8.00 (s, 1H), 7.90 (d, *J* = 8.4 Hz, 2H), 7.69-7.62 (m, 2H), 7.29 (s, 1H), 4.25 (q, *J* = 7.1 Hz, 2H), 1.21 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.39 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.3, 134.3, 132.6, 132.3, 131.6 (q, *J* = 5.0 Hz), 128.9 (q, *J* = 310.1 Hz), 128.5, 128.3, 127.8, 127.6, 127.4, 126.6, 124.1, 61.7, 14.2; IR (thin film) ν 2984, 1716, 1587, 1371, 1238, 1111, 905, 732 cm^{-1}; MS (ESI): *m/z* 405 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{16}H_{13}BrF_3O_2S$ $[M+H]^+$: 404.9766; Found: 404.9763.

*3.2.14. (E)-Ethyl 2-(6-methoxynaphthalen-2-yl)-3-(trifluoromethylthio)acrylate (**2n**)*

Yield 66% (47.1 mg), red oil, eluent for column chromatography: hexane/EtOAc (30:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.86 (s, 1H), 7.78-7.72 (m, 2H), 7.64 (s, 1H), 7.32 (d, *J* = 10.0 Hz, 1H), 7.19-7.15 (m, 2H), 4.29 (q, *J* = 7.1 Hz, 2H), 3.92 (s, 3H), 1.26 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.09 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.3, 158.5, 134.6, 133.7, 131.2 (q, *J* = 3.0 Hz), 129.7, 129.0 (q, *J* = 311.1 Hz), 128.8, 128.4, 128.3, 127.2, 126.9, 119.5, 105.8, 61.6, 55.4, 14.2; MS (ESI): *m/z* 357 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{17}H_{16}F_3O_3S$ $[M+H]^+$: 357.0767; Found: 357.0764.

*3.2.15. (E)-Ethyl 2-(benzofuran-5-yl)-3-(trifluoromethylthio)acrylate (**2o**)*

Yield 61% (38.6 mg), red oil, eluent for column chromatography: hexane/EtOAc (15:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.80 (s, 1H), 7.65 (d, *J* = 2.1 Hz, 1H), 7.53 (d, *J* = 8.6 Hz, 1H), 7.46 (s, 1H), 7.15 (d, *J* = 6.9 Hz, 1H), 6.77 (d, *J* = 1.2 Hz, 1H), 4.26 (q, *J* = 7.1 Hz, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -42.05 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.3, 154.9, 145.8, 133.8, 131.4 (q, *J* = 3.0 Hz), 128.9 (q, *J* = 310.1 Hz), 128.2, 127.7, 125.2, 122.0, 111.7, 106.8, 61.7, 14.3; IR (thin film) ν 2984, 1715, 1468, 1368, 1236, 1109, 1032, 908 cm^{-1}; MS (ESI): *m/z* 317 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{14}H_{12}F_3O_3S$ $[M+H]^+$: 317.0454; Found: 317.0452.

*3.2.16. 1-Benzyl-3-((trifluoromethylthio)methylene)indolin-2-one (**4a**)*

Yield 78% (53.2 mg), brown solid, eluent for column chromatography: hexane/EtOAc (6:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 (s, 0.40H), 7.57 (s, 0.60H), 7.46 (d, *J* = 7.6 Hz, 0.60H), 7.41 (d, *J* = 7.6 Hz, 0.40H), 7.35-7.20 (m, 6H), 7.09-7.04 (m, 1H), 6.78 (d, *J* = 8.0 Hz, 0.60H), 6.75 (d, *J* = 8.0 Hz, 0.40H), 4.97 (s, 1.20H), 4.96 (s, 0.80H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.83 (s, 1.2F), -44.30 (s, 1.8F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.6, 165.2, 142.9, 141.7, 135.6, 135.5, 130.1, 129.4, 129.0 (q, *J* = 311.1Hz), 128.8, 128.5 (q, *J* = 311.1 Hz), 127.8, 127.7, 127.4, 127.2, 125.1 (q, *J* = 4.0 Hz), 125.0, 124.6 (q, *J* = 4.0 Hz), 124.1, 122.5, 122.4, 119.9, 109.5, 109.4, 43.8, 43.7; IR (thin film) ν 2925, 1694, 1610, 1496, 1335, 1115, 906, 771 cm^{-1}; MS (ESI): *m/z* 336 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{17}H_{13}F_3NOS$ $[M+H]^+$: 336.0664; Found: 336.0663.

*3.2.17. 1-Methyl-3-((trifluoromethylthio)methylene)indolin-2-one (**4b**)*

Yield 70% (36.3 mg), brown solid, eluent for column chromatography: hexane/EtOAc (10:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.73 (s, 0.25H), 7.51 (s, 0.75H), 7.46-7.31 (m, 2H), 7.12-7.07 (m, 1H), 6.88-6.84 (m, 1H), 3.28 (s, 2.25H), 3.26 (s, 0.75H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.86 (s, 0.75F), -44.35 (s, 2.25F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.6, 142.6, 130.1, 129.5 (q, *J* = 311.1 Hz), 129.4, 124.7 (q, *J* = 4.0 Hz), 124.0, 122.4, 122.3, 120.8, 119.9, 108.5, 108.3, 29.7, 25.9; IR (thin film) ν 2925, 1682, 1609, 1469, 1379, 1281, 1117, 906 cm^{-1}; MS (ESI): *m/z* 260 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{11}H_9F_3NOS$ $[M+H]^+$: 260.0351; Found: 260.0351.

*3.2.18. 1-Phenyl-3-((trifluoromethylthio)methylene)indolin-2-one (**4c**)*

Yield 73% (46.9 mg), brown solid, eluent for column chromatography: hexane/EtOAc (8:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84 (s, 0.33H), 7.64 (s, 0.67H), 7.56-7.41 (m, 6H), 7.29 (s, 0.33H), 7.25 (s, 0.67H), 7.16-7.12 (m, 1H), 6.92 (d, *J* = 6.92 Hz, 0.67 H), 6.86 (d, *J* = 6.86 Hz, 0.33 H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.78 (s, 1F), -44.37 (s, 2F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.0, 164.5, 143.7, 142.5 133.9, 130.1, 129.7, 129.6, 129.5 (q, *J* = 311.1 Hz), 129.4, 128.5 (q, *J* = 311.1 Hz), 128.2, 128.2, 126.6, 126.2, 125.7 (q, *J* = 4.0 Hz), 124.9 (q, *J* = 4.0 Hz), 124.3, 123.0, 122.9, 121.0, 120.1, 110.0, 109.7; MS (ESI): *m/z* 322 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{16}H_{11}F_3NOS$ $[M+H]^+$: 322.0508; Found: 322.0506.

*3.2.19. 1-Benzyl-5-methoxy-3-((trifluoromethylthio)methylene)indolin-2-one (**4d**)*

Yield 74% (54.0 mg), brown solid, eluent for column chromatography: hexane/EtOAc (9:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81 (s, 0.5H), 7.54 (s, 0.5H), 7.32-7.28 (m, 5H), 7.03 (d, *J* = 2.4 Hz, 0.5H), 7.02 (d, *J* = 2.4 Hz, 0.5H), 6.77-6.74 (m, 1H), 6.66-6.61 (m, 1H), 4.94 (s, 2H), 3.80 (s, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.78 (s, 1.5F), -44.30 (s, 1.5F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 166.6, 165.1, 155.9, 155.7, 136.6, 135.7, 135.6, 129.5 (q, *J* = 311.1 Hz), 128.8, 128.5 (q, *J* = 310.1 Hz), 127.8, 127.7, 127.5, 127.4, 127.3, 125.2 (q, *J* = 4.0 Hz), 124.8 (q, *J* = 4.0 Hz), 121.8, 121.6, 114.9, 114.5, 111.4, 110.2, 109.8, 106.3, 55.9, 43.9, 43.8; IR (thin film) ν 2934, 1691, 1593, 1484, 1364, 1287, 1104, 1021 cm^{-1}; MS (ESI): *m/z* 366 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{18}H_{15}F_3NO_2S$ $[M+H]^+$: 366.0770; Found: 366.0770.

*3.2.20. 1-Benzyl-5-bromo-3-((trifluoromethylthio)methylene)indolin-2-one (**4e**)*

Yield 70% (57.6 mg), brown solid, eluent for column chromatography: hexane/EtOAc (3:1). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.88 (s, 0.45H), 7.62 (s, 0.55H), 7.59 (d, *J* = 2.1 Hz, 0.55H), 7.51 (d, *J* = 2.1 Hz, 0.45H), 7.35-7.28 (m, 6H), 6.64 (d, *J* = 8.4 Hz, 0.55H), 6.62 (d, *J* = 8.4 Hz, 0.45H), 4.96 (s, 1.1H), 4.95 (s, 0.9H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.62 (s, 1.35F), -44.19 (s, 1.65F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 164.8, 141.7, 135.1, 133.5 (q, *J* = 311.1 Hz), 132.6, 129.5 (q, *J* = 310.1 Hz), 128.9, 128.0, 127.9 (q, *J* = 4.4 Hz), 127.7, 127.3, 127.2, 126.9, 126.6 (q, *J* = 4.0 Hz), 125.0, 123.0, 122.4, 115.1, 111.0, 110.8,

43.9, 43.8; IR (thin film) ν 2936, 1706, 1604, 1471, 1338, 1106, 908, 730 cm^{-1}; MS (ESI): *m/z* 414 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{17}H_{12}BrF_3NOS$ $[M+H]^+$: 413.9770; Found: 413.9768.

3.3. General procedure for dehydroxytrifluoromethylthiolation of phenols

A 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with $AgSCF_3$ (417.9 mg, 2.0 mmol), *n*-Bu_4NI (2.22 g, 6.0 mmol), and KI (664.0 mg, 4.0 mmol). The tube was evacuated and backfilled with N_2 for three times. Then, phenol (0.5 mmol) and xylene (5.0 mL) were added to the tube. The tube was placed into a preheated oil bath at 150 °C with vigorous stirring. After 5 h, the reaction mixture was cooled to room temperature and filtered through a plug of silica (eluted with EtOAc). The filtrate was concentrated, and the product was purified by column chromatography on silica gel to give the desired product.

*3.3.1. 4-(Trifluoromethylthio)benzonitrile (**6a**)*

Yield 47% (47.8 mg), white solid, eluent for column chromatography: hexane/EtOAc (10:1). ^1H NMR (400 MHz, $CDCl_3$): δ 7.76 (d, *J* = 8.0 Hz, 2H), 7.72 (d, *J* = 8.4 Hz, 2H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.95 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 136.0, 132.9, 132.6 (q, *J* = 3.0 Hz), 129.0 (q, *J* = 310.1 Hz), 117.6, 114.6; MS (ESI): *m/z* 204 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_8H_5F_3NS$ $[M+H]^+$: 204.0089; Found: 204.0091.

*3.3.2. Ethyl 3-nitro-4-(trifluoromethylthio)benzoate (**6b**)*

Yield 62% (91.5 mg), white solid, eluent for column chromatography: hexane/EtOAc (15:1). ^1H NMR (400 MHz, $CDCl_3$): δ 8.81 (s, 1H), 8.31 (d, *J* = 8.4 Hz, 1H), 7.91 (d, *J* = 8.4 Hz, 1H), 4.46 (q, *J* = 7.2 Hz, 2H), 1.44 (t, *J* = 7.2 Hz, 3H); ^{19}F NMR (376 MHz, $CDCl_3$): δ -41.08 (s, 3F); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.6, 147.7, 134.1, 131.2, 130.6 (q, *J* = 3.0 Hz), 128.6 (q, *J* = 312.1 Hz), 126.7, 62.2, 14.2; MS (ESI): *m/z* 296 $[M+H]^+$; HRMS (ESI-TOF): *m/z* Calculated for $C_{10}H_9F_3NO_4S$ $[M+H]^+$: 296.0199; Found: 291.0196.

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Supplementary Material

Supplementary data associated with this article can be found, in the online version, at doi:XXX/XXX.