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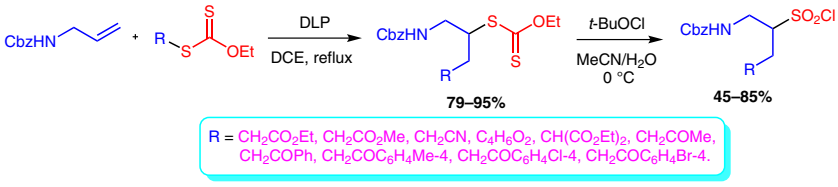
Efficient Synthesis of *N*-Benzyloxycarbonyl-2-aminoalkanesulfonyl Chlorides with Functionalized Side Chains

Hassane Abdellaoui
Xingpeng Chen
Jiaxi Xu*

State Key Laboratory of Chemical Resource Engineering, Department of Organic Chemistry, Faculty of Science, Beijing University of Chemical Technology, Beijing 100029, P. R. of China
hasabdel89@hotmail.fr
chenxp7613@163.com
jxxu@mail.buct.edu.cn



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Abstract *N*-Benzyloxycarbonyl (Cbz)-protected 2-aminoalkanesulfonyl chlorides are useful building blocks for the synthesis of sulfonopeptides, which are receptor ligands and enzyme inhibitors, and are prepared by the coupling reaction of N-protected aminoalkanesulfonyl chlorides with amino acid or peptide esters. Various *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides with functionalized side chains were synthesized through the radical addition of different xanthates to benzyl *N*-allylcarbamate and subsequent oxidative chlorination with *tert*-butyl hypochlorite under neutral conditions. A mechanism for the oxidative chlorination is proposed. This is a useful and convenient strategy for the synthesis of *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides with diverse functionalized side-chains.

Key words oxidative chlorination, radical reaction, sulfonyl chlorides, xanthate, aminoalkanesulfonyl chloride

Sulfonopeptides are a class of peptides containing at least one 2-aminoalkanesulfonic acid residue in their peptide chains.[1] They have been widely applied as receptor ligands and enzyme inhibitors,[1,2] such as inhibitors of leukocyte adhesion,[3] HIV protease,[4] and bacterial peptidoglycan biosynthesis enzymes,[5] etc. (Figure 1), because the tetrahedral sulfonamide is the mimic analogue of the transition states of the amide and ester hydrolysis. The general method for the synthesis of sulfonopeptides is the coupling of N-protected 2-aminoalkanesulfonyl chlorides and amino ester or peptide esters.[1,2,6] Thus, N-protected 2-aminoalkanesulfonyl chlorides are building blocks for the synthesis of sulfonopeptides. The synthetic methods for N-protected 2-aminoalkanesulfonyl chlorides include (1) chlorination of N-protected 2-aminoalkanesulfonic acids or their sodium salts with chlorinating reagents,[7] and (2) the direct oxidative chlorination of N-protected 2-aminoalkanethiols or their derivatives.[8] *N*-Benzyloxycarbonyl (Cbz)-protected 2-aminoalkanesulfonyl chlorides are the most useful building blocks in the solid- and solution-phase peptide synthetic processes.[9] Although various *N*-Cbz 2-aminoalkanesulfonyl chlorides have been prepared,[7,8] only a few *N*-Cbz 2-aminoalkanesulfonyl chlorides with functionalized side-chains have been synthesized via multi-step procedures.[10] However, most biologically active peptides contain amino acid residues with different functionalized side-chains.[3,5] There is considerable and still increasing interest in the synthesis of *N*-Cbz 2-aminoalkanesulfonyl chlorides with functionalized side chains. Herein, we report the synthesis of *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides with diverse functionalized side chains through the radical addition of various xanthates to benzyl *N*-allylcarbamate and subsequent oxidative chlorination with *tert*-butyl hypochlorite under neutral conditions.

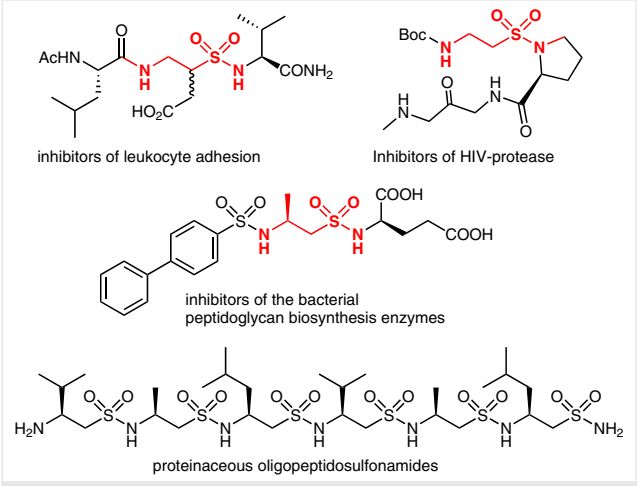
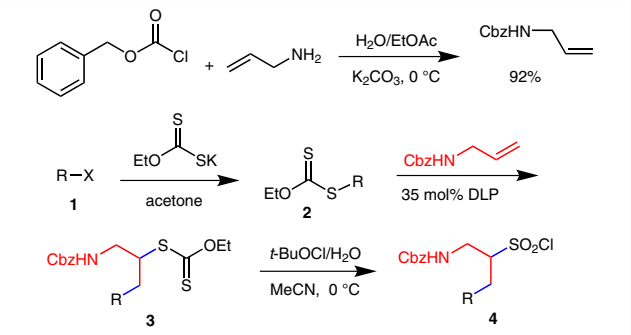


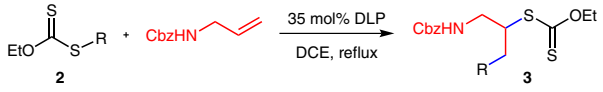
Figure 1 Representative biological sulfonopepetides

Benzyl *N*-allylcarbamate was prepared from benzyl chloroformate and allylamine in 92% yield.[11] Different xanthates **2** were synthesized from potassium *O*-ethylxanthate and the corresponding halo derivatives **1**.[12] Radical addition of various xanthates to different olefins has been well developed by Zard group.[13] Reactions of different xanthates **2** with benzyl *N*-allylcarbamate under radical initiator dilauroyl peroxide (DLP) in 1,2-dichloroethane (DCE) as a solvent afforded a series of *S*-2-Cbz-aminoalkyl xanthates **3** in good to excellent yields (Scheme 1) (Table 1).



Scheme 1 Synthesis of *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides with functionalized side chains

Table 1 Radical Addition of Xanthates **2** with Benzyl *N*-Allylcarbamate

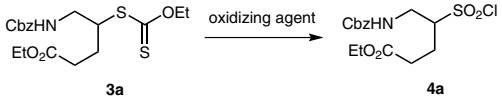


Entry	Xanthate **2**	R	Xanthate **3**	Yield (%)
1	**2a**	CH_2CO_2Et	**3a**	95
2	**2b**	CH_2CO_2Me	**3b**	90
3	**2c**	CH_2CN	**3c**	85
4	**2d**	$CH_2C_4H_6O_2$[a]	**3d**	92
5	**2e**	$CH(CO_2Et)_2$	**3e**	95
6	**2f**	CH_2COMe	**3f**	85
7	**2g**	CH_2COPh	**3g**	92
8	**2h**	$CH_2COC_6H_4Me$-4	**3h**	85
9	**2i**	$CH_2COC_6H_4Cl$-4	**3i**	79
10	**2j**	$CH_2COC_6H_4Br$-4	**3j**	89

[a] 2-Oxotetrahydrofuran-3-yl.

Oxidative chlorination of xanthate **3a** was selected as a model reaction to optimize the reaction conditions because it possesses a hydrolyzable ester group. When *N*-chlorosuccinimide (NCS) was used as oxidant in different solvent systems,[14] no desired product sulfonyl chloride **4a** was obtained (Table 2, entries 1–6). Oxidative systems KNO_3/TMSCl in dichloromethane[15] and $TiCl_4/H_2O_2$ in acetonitrile[16] did not produce the desired product as well (entries 7 and 8). Neither $NaClO_2$ nor NaClO are efficient oxidants in the oxidative chlorination (entries 9 and 10) although they worked well in the preparation of alkanesulfonyl chlorides.[17] However, *N*-benzyloxycarbonyl-protected 2-aminoalkanesulfonyl chloride **4a** was obtained by using *tert*-butyl hypochlorite (*t*-BuOCl) at 0 °C in a mixture of water and acetonitrile under neutral conditions (entry 11). The yield was further improved when the amount of water was decreased (entry 12).

Table 2 Optimization of Oxidative Chlorination of Xanthate **3a** to Sulfonyl Chloride **4a**[a]



3a **4a**

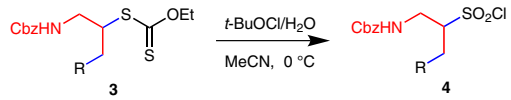
Entry	Solvent (v/v)	Oxidant (equiv)	Temp (°C)	Yield (%)[b]
1	H_2O/MeCN (1:5)	NCS (4)	15	–
2	AcOH/H_2O (3:1)	NCS (4)	15	–
3	H_2SO_4 (2 mol/L)/MeCN (1:5)	NCS (4)	15	–
4	HCl (2 mol/L)/MeCN (1.2:7)	NCS (6)	20	–
5	HCl (2 mol/L)/MeCN (0.4:2)	NCS (6)	20	–
6	AcOH/MeCN (3:1)	NCS (6)	20	–
7	CH_2Cl_2 (5)	KNO_3/TMSCl (5:5)	50	–
8	MeCN (5)	$TiCl_4/H_2O_2$ (1:3)	25	–
9	concd HCl/MeCN (3:10)	$NaClO_2$ (3)	10–20	–
10	H_2SO_4 (6 mol/L)/H_2O (2:2)	NaClO (0.05)	0–20	–
11	H_2O/MeCN (0.1:1.5)	*t*-BuOCl (5)	0	79
12	H_2O/MeCN (0.08:1.2)	*t*-BuOCl (4)	0	85

[a] All reactions were run on 1 mmol scale of xanthate **3a**.
[b] Isolated yields.

Under the optimized conditions, all xanthates **3** were converted into *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides **4** in satisfactory to good yields. Under the current oxidative chlorination conditions, all functional groups on the side-chains of *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides **4** are tolerated (Table 3) (Scheme 1).

We have previously investigated oxidation of xanthates[18] and thioacetates,[19] and oxidative chlorination of thioacetates[6a,8] and *S*-alkylthiouriniums.[14,17] Douglass and his co-workers studied chlorination of xanthates and related sulfur-containing compounds.[20] They reported that xanthates ($ROCS_2R'$) were chlorinated into alkoxydichloromethanesulfenyl chlorides ($ROCCl_2SCl$) and alkylsulfur trichlorides ($R'SCl_3$) with chlorine under anhydrous conditions.[20b] On the basis of the above results, the mechanism on the oxidative chlorination of xanthates **3** into *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides **4** with *t*-BuOCl was proposed as depicted in Scheme 2. In the first

Table 3 Synthesis of *N*-Cbz-2-aminoalkanesulfonyl Chlorides **4**



Entry	Xanthate **3**	R	Sulfonyl chloride **4**	Yield (%)
1	**3a**	CH_2CO_2Et	**4a**	85
2	**3b**	CH_2CO_2Me	**4b**	76
3	**3c**	CH_2CN	**4c**	45
4	**3d**	$CH_2C_4H_6O_2$[a]	**4d**	52
5	**3e**	$CH(CO_2Et)_2$	**4e**	55
6	**3f**	CH_2COMe	**4f**	63
7	**3g**	CH_2COPh	**4g**	83
8	**3h**	$CH_2COC_6H_4Me$-4	**4h**	47
9	**3i**	$CH_2COC_6H_4Cl$-4	**4i**	71
10	**3j**	$CH_2COC_6H_4Br$-4	**4j**	60

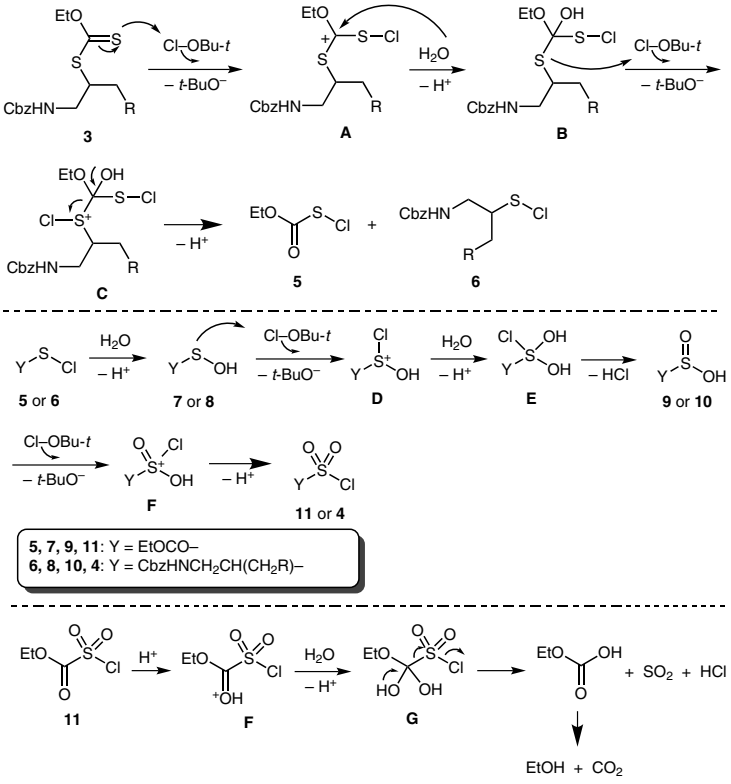
[a] 2-Oxotetrahydrofuran-3-yl.

step, the sulfur atom in the thioxo part of xanthates **3** attacks the chlorine atom in *t*-BuOCl, generating chlorothiocarbocations **A**. Intermediates **A** are attacked by water in the reaction system to afford intermediates **B**, which are further chlorinated by another molecule of *t*-BuOCl to give *S*-chlorothioetheriums **C**. Intermediates **C** are unstable and decompose into ethoxycarbonylsulfenyl chloride (**5**) and *N*-Cbz 2-aminoalkanesulfenyl chlorides **6** by loss of a proton.

Both ethoxycarbonylsulfenyl chloride (**5**) and *N*-Cbz 2-aminoalkanesulfenyl chlorides **6** are further oxidatively chlorinated into the corresponding sulfonyl chlorides **11** and **4**, respectively, following the same mechanism. First, sulfenyl chlorides **5** and **6** are hydrolyzed with water in the reaction system into the corresponding sulfenic acids **7** and **8**, which are chlorinated into *S*-chlorosulfurium intermediates **D** with *t*-BuOCl. Intermediates **D** are attacked by water to generate intermediates **E**, which further eliminate a molecule of HCl to yield the corresponding sulfinic acids **9** and **10**. The sulfinic acids **9** and **10** are chlorinated again with *t*-BuOCl followed by loss of a proton, affording the corresponding sulfonyl chloride **11** and **4**.

Ethoxycarbonylsulfonyl chloride (**11**) is unstable. Its carbonyl group is more electrophilic. After protonation, the protonated carbonyl group in the intermediate **F** is attacked predominantly by water in the reaction system, generating intermediate **G**, which is more unstable and finally decomposes into ethanol, CO_2, SO_2, and HCl (Scheme 2).

In summary, *N*-benzyloxycarbonyl (Cbz)-protected 2-aminoalkanesulfonyl chlorides are useful building blocks for the solution- and solid-phase synthesis of sulfonopep-



Scheme 2 Plausible mechanism for the oxidative chlorination of *S*-2-Cbz-aminoalkyl xanthates **3** to *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides **4**

tides. Various *N*-Cbz-protected 2-aminoalkanesulfonyl chlorides with functionalized side-chains were synthesized from the radical addition of different functionalized xanthates to benzyl *N*-allylcarbamate and subsequent oxidative chlorination with *tert*-butyl hypochlorite under neutral conditions. The current strategy is a useful and convenient synthesis of *N*-Cbz-protected taurinesulfonyl chlorides with diverse functionalized side chains.

Melting points were measured on a Yanaco MP-500 melting point apparatus and are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded on Bruker 400 spectrometer in $CDCl_3$ with TMS as an internal standard. IR spectra were recorded on a Nicolet AVATAR 330 FTIR spectrometer. HRMS spectra were recorded with an LC/MSD TOF mass spectrometer. All reactions were performed under N_2 atmosphere. TLC analysis was performed on glass pre-coated silica gel YT257–85 (10–40 µm) plate. Spots were visualized with UV light or I_2. Column chromatography was performed on silica gel zcx II (200–300 mesh) with a mixture of PE and EtOAc as the eluent.

Benzyl *N*-Allylcarbamate[11]

A round-bottomed flask equipped with a magnetic stirring bar was charged with allylamine (0.57 g, 10 mmol), K_2CO_3 (0.35 g, 25 mmol), H_2O (15 mL), and EtOAc (15 mL). The flask was cooled in an ice-water bath and 95% of benzyl chloroformate (1.79 g, 10.5 mmol) was added over 30 min by using a syringe pump. After stirring at r.t. for 2 h, the organic layer was separated and washed with aq 1 mol/L HCl (2 × 10 mL) and brine (10 mL). The combined organic phase was dried ($MgSO_4$). After removal of solvents on a rotary evaporator, the residue was purified by flash chromatography on silica gel to give the desired benzyl *N*-allylcarbamate as a colorless oil; yield: 1.72 g (90%).

^{1}H NMR ($CDCl_3$, 400 MHz): δ = 7.35–7.32 (m, 5 H, ArH), 5.83 (ddt, *J* = 17.1, 10.5, 5.3 Hz, 1 H, CH), 5.18 (dd, *J* = 17.1, 1.4 Hz, 1 H, CH), 5.12 (dd, *J* = 10.5, 1.4 Hz, 1 H, CH), 5.11 (s, 2 H, OCH_2), 4.84 (br s, 1 H, NH), 3.81 (t, *J* = 7.6 Hz, 2 H, CHN).

^{13}C NMR ($CDCl_3$, 100 MHz): δ = 156.2, 136.5, 134.4, 128.4, 128.0, 115.9, 66.7, 43.4.

Xanthates 2; General Procedure

To a solution of a haloalkane derivative **1** (25.0 mmol) in acetone (12 mL) precooled at 0 °C was added a solution of potassium *O*-ethyl dithiocarbonate (**2**; 4.00 g, 25.0 mmol) in acetone (25 mL) slowly under stirring at 0 °C. After the addition, the mixture was allowed to warm to r.t. under stirring. After evaporation of acetone, H_2O (50 mL) was added to the residue and the mixture was extracted with $CHCl_3$ (3 × 50 mL). The combined organic phases were dried ($MgSO_4$). After removal of solvents on a rotary evaporator, the residue was purified on a silica gel column with PE and EtOAc (from 20:1 to 10:1, v/v) as eluent to afford the desired xanthate **2**.

The analytic data of xanthates **2** are identical to the reported ones.[6a]

O-Ethyl *S*-2-Cbz-aminoalkyl Xanthates 3; General Procedure

A magnetically stirred solution of benzyl *N*-allylcarbamate (1 equiv) and a xanthate **2** (2–4 equiv) in 1,2-dichloroethane (2–4 mL/mmol of benzyl *N*-allylcarbamate) was heated at reflux for 15 min. DLP (3–5 mol %) was added and then additional DLP (5 mol %) was added per hour until complete consumption of benzyl *N*-allylcarbamate. The mixture was allowed to cool to r.t. and the solvent was evaporated under reduced pressure. The residue was purified by flash chromatography on silica gel with a mixture of PE and EtOAc (10:1, v/v) as eluent to afford the desired product **3**.

Ethyl 5-{[(Benzyloxy)carbonyl]amino}-4-[(ethoxycarbonothioyl)thio]pentanoate (3a)

Yellow oil; yield: 1.90 g (95%, on 5 mmol scale).

IR (KBr): 3348, 2981, 1702, 1604, 1521, 1449, 1223, 1050 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.31 (br s, 5 H, ArH), 5.16 (d, *J* = 5.3 Hz, 1 H, NH), 5.10 (s, 2 H, OCH_2), 4.62 (q, *J* = 7.0 Hz, 2 H, CH_2), 4.13 (q, *J* = 7.1 Hz, 2 H, CH_2), 3.95–3.85 (m, 1 H, CHS), 3.60–3.50 (m, 1 H in CH_2), 3.50–3.38 (m, 1 H in CH_2), 2.55–2.47 (m, 2 H, CH_2), 2.16–2.01 (m, 1 H in CH_2), 1.95–1.85 (dd, *J* = 14.7, 6.5 Hz, 1 H in CH_2), 1.40 (t, *J* = 7.1 Hz, 3 H, CH_3), 1.25 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.1, 172.7, 156.4, 136.4, 128.5, 128.2, 105.0, 77.3, 66.9, 60.6, 51.0, 44.3, 31.5, 26.5, 14.2, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{26}NO_5S_2^+$: 400.1247 [M + H]$^+$; found: 400.1251.

Methyl 5-{[(Benzyloxy)carbonyl]amino}-4-[(ethoxycarbonothioyl)thio]pentanoate (3b)

Yellow oil; yield: 0.986 g (90%, on 3 mmol scale).

IR (KBr): 3349, 2947, 1729, 1602, 1523, 1451, 1224, 1051 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.31 (br s, 5 H, ArH), 5.18 (s, 1 H, CHN), 5.10 (s, 2 H, OCH_2), 4.62 (q, *J* = 7.0 Hz, 2 H, OCH_2), 3.93–3.83 (m, 1 H, SCH), 3.67 (s, 3 H, CH_3), 3.60–3.51 (m, 1 H in CH_2), 3.48–3.37 (m, 1 H in CH_2), 2.55–2.46 (m, 2 H, CH_2), 2.11–2.05 (m, 1 H in CH_2), 1.94–1.80 (m, 1 H in CH_2), 1.41 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.0, 173.1, 156.4, 136.3, 128.4, 128.1, 128.0, 70.3, 66.8, 51.7, 50.9, 44.2, 31.1, 26.4, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{17}H_{24}NO_5S_2^+$: 386.1090 [M + H]$^+$; found: 386.1074.

Benzyl 4-Cyano-2-(ethoxycarbonothioylthio)butylcarbamate (3c)[21]

Yellow oil; yield: 0.898 g (85%, 3 mmol scale).

IR (KBr): 3348, 2932, 2244, 1721, 1519, 1231, 1046 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35 (s, 5 H, ArH), 5.16 (s, 1 H, NH), 5.10 (s, 2 H, CH_2), 4.64 (q, *J* = 7.0 Hz, 2 H, CH_2), 3.98–3.90 (m, 1 H, CH), 3.60–3.45 (m, 2 H, CH_2), 2.65–2.47 (m, 2 H, CH_2), 2.22–2.08 (m, 1 H in CH_2), 1.99–1.82 (m, 1 H in CH_2), 1.42 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 211.8, 156.5, 136.1, 128.5, 128.2, 128.1, 118.7, 70.7, 67.1, 50.4, 43.7, 27.3, 15.0, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{21}N_2O_3S_2^+$: 353.0988 [M + H]$^+$; found: 353.0960.

Benzyl [2-(Ethoxycarbonothioyl)thio-3-(2-oxotetrahydrofuran-3-yl)propyl]carbamate (3d)

Yellow oil; yield: 1.095 g (92%, 3 mmol scale). Two pairs of diastereomers exist due to the presence of two chiral carbon atoms.

IR (KBr): 3364, 2943, 1713, 1617, 1520, 1221, 1048 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.33 (br s, 5 H, ArH), 5.20 (d, *J* = 6.0 Hz, 1 H, NH), 5.10 (s, 2 H, OCH_2), 4.63 (q, *J* = 7.0 Hz, 2 H), 4.38–4.30 (m, 1 H, CH), 4.23–4.16 (m, 1 H in CH_2), 4.16–3.98 (m, 1 H in CH_2), 3.71–3.53 (m, 1 H in CH_2), 3.52–3.41 (m, 1 H in CH_2), 2.89–2.75 (m, 1 H,

CHCO), 2.52–2.39 (m, 1 H in CH_2CO), 2.33–2.17 (m, 1 H in CH_2CS), 2.03–1.92 (m, 1 H in CH_2CO), 1.87–1.69 (m, 1 H in CH_2CS), 1.41 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.0 (212.6), 178.6, 156.5, 136.3, 128.5, 128.1, 128.0, 70.4 (70.6), 66.4 (66.9), 50.0 (49.8), 44.8, 43.7, 37.2, 31.9 (32.3), 29.3, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{24}NO_5S_2^+$: 398.1090 [M + H]$^+$; found: 398.1056.

Diethyl 2-[3-Benzyloxycarbonylamino-2-(ethoxycarbonothioyl)thiopropyl]malonate (3e)

Yellow oil; yield: 1.342 g (95%, 3 mmol scale).

IR (KBr): 3367, 2979, 1711, 1610, 1540, 1450, 1221, 1052 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.31 (br s, 5 H, ArH), 5.14 (s, 1 H, NH), 5.10 (s, 2 H, OCH_2), 4.62 (q, *J* = 7.0 Hz, 2 H, CH_2O), 4.20 (q, *J* = 7.0 Hz, 2 H, CH_2O), 4.19 (q, *J* = 7.0 Hz, 2 H, CH_2O), 3.96–3.84 (m, 1 H, CH), 3.70–3.59 (m, 1 H, CHCO), 3.58–3.46 (m, 2 H, CH_2), 2.47–2.35 (m, 1 H in CH_2), 2.16–2.05 (m, 1 H in CH_2), 1.40 (t, *J* = 7.0 Hz, 3 H, CH_3), 1.26 (t, *J* = 7.1 Hz, 6 H, 2 × CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 212.8, 169.0, 168.8, 156.5, 136.5, 128.6, 128.23, 128.17, 70.6, 67.0, 61.9, 61.8, 49.8, 49.6, 44.6, 30.3, 14.15, 14.12, 13.8.

HRMS (ESI): *m*/*z* calcd for $C_{21}H_{30}NO_7S_2^+$: 472.1458 [M + H]$^+$; found: 472.1434.

Benzyl [2-(Ethoxycarbonothioyl)thio-5-oxohexyl]carbamate (3f)

Yellow oil; yield: 0.94 g (85%, 3 mmol scale).

IR (KBr): 3338, 2926, 1715, 1605, 1520, 1222, 1051 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.31 (br s, 5 H, ArH), 5.18 (s, 1 H, NH), 5.10 (s, 2 H, CH_2), 4.62 (q, *J* = 7.1 Hz, 2 H, CH_2), 3.87–3.78 (m, 1 H, CH), 3.62–3.49 (m, 1 H in CH_2), 3.47–3.35 (m, 1 H in CH_2), 2.63 (t, *J* = 7.2 Hz, 2 H, CH_2), 2.13 (s, 3 H, CH_3), 2.10–2.00 (m, 1 H in CH_2), 1.87–1.75 (m, 1 H in CH_2), 1.41 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.3, 207.5, 156.5, 136.4, 128.5, 128.2, 128.1, 70.4, 66.9, 51.0, 44.3, 40.5, 30.0, 24.9, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{17}H_{24}NO_4S_2^+$: 370.1141 [M + H]$^+$; found: 370.1131.

Benzyl [2-(Ethoxycarbonothioyl)thio-5-oxo-5-phenylpentyl]carbamate (3g)

Yellow oil; yield: 1.19 g (92%, 3 mmol scale).

IR (KBr): 3336, 2935, 1686, 1599, 1520, 1370, 1182, 1005 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.95 (d, *J* = 7.5 Hz, 2 H, ArH), 7.56 (t, *J* = 7.4 Hz, 1 H, ArH), 7.45 (t, *J* = 7.6 Hz, 2 H, ArH), 7.35–7.26 (m, 5 H, ArH), 5.23 (s, 1 H, NH), 5.10 (s, 2 H, CH_2O), 4.60 (q, *J* = 6.8 Hz, 2 H, CH_2), 4.00–3.95 (m, 1 H, CH), 3.68–3.53 (m, 1 H in CH_2), 3.52–3.47 (m, 1 H in CH_2), 3.18 (t, *J* = 7.2 Hz, 2 H, CH_2), 2.30–2.23 (m, 1 H in CH_2), 2.04–1.96 (m, 1 H in CH_2), 1.38 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.1, 198.9, 156.4, 136.6, 136.3, 133.1, 128.6, 128.5, 128.1, 128.02, 127.99, 70.3, 66.8, 51.0, 44.3, 35.5, 25.4, 13.6.

HRMS (ESI): *m*/*z* calcd for $C_{22}H_{26}NO_4S_2^+$: 432.1298 [M + H]$^+$; found: 432.1295.

Benzyl [2-(Ethoxycarbonothioyl)thio-5-oxo-5-(4-methylphenyl)pentyl]carbamate (3h)

Yellow oil; yield: 1.135 g (85%, 3 mmol scale).

IR (KBr): 3344, 2939, 1715, 1611, 1521, 1451, 1363, 1224, 1052 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.85 (d, *J* = 8.2 Hz, 2 H, ArH), 7.31 (br s, 5 H, ArH), 7.24 (d, *J* = 8.2 Hz, 2 H, ArH), 5.22 (s, 1 H, NH), 5.10 (s, 2 H, CH_2), 4.60 (q, *J* = 6.8 Hz, 2 H, CH_2), 3.97–3.89 (m, 1 H, CH), 3.61–3.53 (m, 1 H in CH_2), 3.56–3.47 (m, 1 H in CH_2), 3.13 (t, *J* = 6.8 Hz, 2 H, CH_2), 2.40 (s, 3 H, CH_3), 2.28–2.17 (m, 1 H in CH_2), 2.03–1.96 (m, 1 H in CH_2), 1.39 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.2, 198.6, 156.5, 144.0, 136.4, 134.2, 129.3, 128.5, 128.2, 128.15, 128.10, 70.3, 66.9, 51.1, 44.4, 35.5, 25.5, 21.7, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{23}H_{28}NO_4S_2^+$: 446.1454 [M + H]$^+$; found: 446.1462.

Benzyl [5-(4-Chlorophenyl)-2-(ethoxycarbonothioyl)thio-5-oxopentyl]carbamate (3i)

Yellow oil; yield: 1.102 g (79%, 3 mmol scale).

IR (KBr): 3347, 2928, 1713, 1590, 1489, 1361, 1223, 1049 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.4 Hz, 2 H, ArH), 7.43 (d, *J* = 8.4 Hz, 2 H, ArH), 7.32 (br s, 5 H, ArH), 5.21 (s, 1 H, NH), 5.10 (s, 2 H, CH_2), 4.60 (q, *J* = 7.0 Hz, 2 H), 3.98–3.89 (m, 1 H, CH), 3.67–3.55 (m, 1 H in CH_2), 3.54–3.43 (m, 1 H in CH_2), 3.14 (t, *J* = 6.8 Hz, 2 H, CH_2), 2.28–2.19 (m, 1 H in CH_2), 2.03–1.96 (m, 1 H in CH_2), 1.39 (t, *J* = 6.8 Hz, 3 H).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.1, 197.7, 156.5, 139.7, 136.4, 135.0, 129.5, 129.0, 128.5, 128.2, 128.1, 70.4, 66.9, 51.1, 44.4, 35.6, 25.4, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{22}H_{25}ClNO_4S_2^+$: 466.0908 [M + H]$^+$; found: 466.0915.

Benzyl [5-(4-Bromophenyl)-2-(ethoxycarbonothioyl)thio-5-oxopentyl]carbamate (3j)

Yellow oil; yield: 1.36 g (89%, 3 mmol scale).

IR (KBr): 3346, 2935, 1690, 1586, 1519, 1451, 1224, 1050 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.81 (d, *J* = 8.4 Hz, 2 H, ArH), 7.59 (d, *J* = 8.4 Hz, 2 H, ArH), 7.32 (br s, 5 H, ArH), 5.19 (s, 1 H, NH), 5.10 (s, 2 H, CH_2), 4.60 (q, *J* = 6.8 Hz, 2 H, CH_2), 3.98–3.89 (m, 1 H, CH), 3.65–3.55 (m, 1 H in CH_2), 3.55–3.44 (m, 1 H in CH_2), 3.15 (t, *J* = 6.8 Hz, 2 H, CH_2), 2.27–2.18 (m, 1 H in CH_2), 20.3–1.94 (m, 1 H in CH_2), 1.39 (t, *J* = 6.8 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 213.1, 197.9, 156.5, 136.4, 135.4, 132.0, 129.6, 128.6, 128.4, 128.2, 128.1, 70.4, 66.9, 51.1, 44.4, 35.6, 25.4, 13.7.

HRMS (ESI): *m*/*z* calcd for $C_{22}H_{25}BrNO_4S_2^+$: 510.0403 [M + H]$^+$; found: 510.0412.

***N*-Cbz-2-aminoalkanesulfonyl Chlorides 4; General Procedure**[22]

To a mixture of xanthate **3** (1.4 mmol) and H_2O (0.13 mL, 7 mmol) in MeCN (2 mL) at 0 °C was added dropwise *t*-BuOCl (0.79 mL, 7 mmol). The reaction mixture was stirred at 0 °C for 15 min. The mixture was extracted with CH_2Cl_2 (3 × 4 mL). The combined organic phases were washed with H_2O (5 mL) and then dried (Na_2SO_4). After filtration and removal of the solvent in vaccum, the residue was chromatographied on silica gel [PE (60–90 °C)/EtOAc = 5:1, v/v] to afford the desired sulfonyl chloride **4**.

Ethyl 5-Benzyloxycarbonylamino-4-chlorosulfonylpentanoate (4a)

Yellow oil; yield: 449 mg (85%).

IR (KBr): 3352, 2987, 1775, 1713, 1523, 1221, 1050 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.47–7.27 (m, 5 H, ArH), 5.45 (s, 1 H, NH), 5.12 (s, 2 H, CH_2), 4.45–4.33 (m, 1 H, CH), 4.21–4.09 (q, *J* = 7.1 Hz, 2 H, CH_2), 3.94–3.83 (m, 1 H in CH_2), 3.81–3.76 (m, 1 H in CH_2), 2.72–2.53 (m, 2 H, CH_2), 2.44–2.33 (m, 1 H in CH_2), 2.22–2.06 (m, 1 H in CH_2), 1.27 (t, *J* = 7.1 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 171.9, 156.4, 136.0, 128.6, 128.3, 128.2, 74.8, 67.3, 61.1, 40.1, 30.3, 23.0, 14.2.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{21}ClNO_6S^+$: 378.0773 $[M + H]^+$; found: 378.0780.

Methyl 5-Benzyloxycarbonylamino-4-chlorosulfonylpentanoate (4b)

Colorless oil; yield: 386 mg (76%).

IR (KBr): 3345, 2938, 1769, 1730, 1524, 1364, 1224, 1052 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.32 (br s, 5 H, ArH), 5.42 (br, s, 1 H, NH), 5.12 (s, 2 H, CH_2), 3.96–3.87 (m, 1 H, CH), 3.85–3.75 (m, 2 H, CH_2), 3.71 (s, 3 H, CH_3), 2.73–2.61 (m, 2 H, CH_2), 2.48–2.40 (m, 1 H in CH_2), 2.19–2.08 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 172.3, 156.4, 136.0, 128.6, 128.4, 128.2, 74.7, 67.35, 52.1, 40.1, 30.1, 23.0.

HRMS (ESI): *m*/*z* calcd for $C_{14}H_{19}ClNO_6S^+$: 364.0616 $[M + H]^+$; found: 364.0622.

Benzyl (2-Chlorosulfonyl-4-cyanobutyl)carbamate (4c)

Colorless oil; yield: 208 mg (45%).

IR (KBr): 3346, 2941, 2248, 1776, 1708, 1519, 1180, 1003 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.37 (br s, 5 H, ArH), 5.42 (s, 1 H, NH), 5.11 (s, 2 H, CH_2), 3.90–3.71 (m, 3 H, CH, CH_2), 2.74 (t, *J* = 7.2 Hz, 2 H, CH_2), 2.48–2.37 (m, 1 H in CH_2), 2.26–2.14 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 156.6, 135.7, 128.7, 128.5, 128.2, 117.7, 74.0, 67.6, 39.8, 23.7, 14.8.

HRMS (ESI): *m*/*z* calcd for $C_{13}H_{16}ClN_2O_4S^+$: 331.0514 $[M + H]^+$; found: 331.0525.

Benzyl [2-Chlorosulfonyl-3-(2-oxotetrahydrofuran-3-yl)propyl]carbamate (4d)

Colorless oil; yield: 273 mg (52%). Two pairs of diastereomers exist due to the existence of two chiral carbon atoms.

IR (KBr): 3360, 2949, 1779, 1713, 1610, 1520, 1223, 1049 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.35 (br s, 5 H, ArH), 5.46 (br s, 1 H, NH), 5.12 (s, 2 H, CH_2), 4.45–4.32 (m, 2 H, CH_2), 4.30–4.21 (m, 1 H, CH), 4.16–3.97 (m, 1 H in CH_2), 3.95–3.71 (m, 1 H in CH_2), 3.04–2.95 (m, 1 H, CH), 2.50–2.38 (m, 1 H in CH_2), 2.29–2.20 (m, 1 H in CH_2), 2.08–1.85 (m, 2 H, CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 177.8, 156.6, 135.7, 128.6, 128.4, 128.1, 73.1 (73.0), 67.4 (66.6), 39.3 (40.5), 36.4 (35.5), 29.2 (29.0), 27.9.

HRMS (ESI): *m*/*z* calcd for $C_{15}H_{19}ClNO_6S^+$: 376.0616 $[M + H]^+$; found: 376.0621.

Diethyl 2-(3-Benzyloxycarbonylamino-2-chlorosulfonylpropyl)malonate (4e)

Colorless oil; yield: 346 mg (55%).

IR (KBr): 3361, 2982, 1775, 1716, 1610, 1540, 1221, 1051 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.49–7.31 (m, 5 H, ArH), 5.29 (s, 1 H, NH), 5.11 (s, 2 H, CH_2), 4.31 (t, *J* = 6.7 Hz, 1 H), 4.25–4.15 (m, 4 H, 2 CH_2), 3.73–3.59 (m, 2 H, CH_2), 3.53–3.43 (m, 2 H, CH_2), 2.45–2.36 (m, 1 H in CH_2), 2.34–2.22 (m, 1 H in CH_2), 1.28 (t, *J* = 7.0 Hz, 3 H, CH_3), 1.26 (t, *J* = 7.0 Hz, 3 H, CH_3).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 167.9, 167.7, 155.4, 135.6, 129.9, 127.4, 127.0, 65.7, 64.9, 60.7, 49.2, 48.3, 42.0, 28.8, 13.2, 13.0.

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{25}ClNO_8S^+$: 450.0984 $[M + H]^+$; found: 450.0997.

Benzyl (2-Chlorosulfonyl-5-oxohexyl)carbamate (4f)

Colorless oil; yield: 306 mg (63%).

IR (KBr): 3345, 2928, 1776, 1712, 1602, 1519, 1225, 1051 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.45–7.31 (m, 5 H, ArH), 5.28 (s, 2 H, CH_2), 5.11 (br s, 1 H, NH), 4.17 (dd, *J* = 11.3, 6.9 Hz, 1 H in CH_2), 3.83 (dd, *J* = 11.3, 5.5 Hz, 1 H in CH_2), 3.76–3.65 (m, 1 H, CHS), 2.61–2.52 (m, 2 H, CH_2), 2.15 (s, 3 H, CH_3), 2.09 (dd, *J* = 12.7, 7.2 Hz, 1 H in CH_2), 1.99–1.86 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 205.7, 149.6, 133.9, 127.64, 127.56, 127.2, 67.7, 52.1, 39.7, 39.3, 29.0, 27.9.

HRMS (ESI): *m*/*z* calcd for $C_{14}H_{19}ClNO_5S^+$: 348.0667 $[M + H]^+$; found: 348.0669.

Benzyl (2-Chlorosulfonyl-5-oxo-5-phenylpentyl)carbamate (4g)

Yellow oil; yield: 475 mg (83%).

IR (KBr): 3346, 2936, 1773, 1689, 1595, 1524, 1180, 1003 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.96 (d, *J* = 7.6 Hz, 2 H, ArH), 7.59 (t, *J* = 7.6 Hz, 1 H, ArH), 7.47 (t, *J* = 7.6 Hz, 2 H, ArH), 7.32 (br s, 5 H, ArH), 5.49 (s, 1 H, NH), 5.12 (s, 2 H, OCH_2), 4.00–3.90 (m, 1 H, CH), 3.90–3.80 (m, 2 H, CH_2O), 3.46–3.28 (m, 2 H, CH_2), 2.59–2.50 (m, 1 H in CH_2), 2.38–2.25 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 198.0, 156.4, 148.5, 136.2, 136.0, 133.6, 128.7, 128.6, 128.4, 128.1, 75.0, 67.3, 40.3, 34.5, 22.0.

HRMS (ESI): *m*/*z* calcd for $C_{19}H_{21}ClNO_5S^+$: 410.0823 $[M + H]^+$; found: 410.0834.

Benzyl [2-Chlorosulfonyl-5-oxo-5-(4-methylphenyl)pentyl]carbamate (4h)

Colorless oil; yield: 278 mg (47%).

IR (KBr): 3325, 2928, 1776, 1714, 1600, 1521, 1368, 1223, 1051 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): δ = 7.85 (d, *J* = 8.0 Hz, 2 H, ArH), 7.31 (br s, 5 H, ArH), 7.25 (d, *J* = 8.0 Hz, 2 H, ArH), 5.53, 5.24 (s, 1 H, NH), 5.11 (s, 2 H, CH_2), 3.85–3.77 (m, 1 H, CH), 3.59–3.47 (m, 2 H, CH_2), 3.33–2.25 (m, 1 H in CH_2), 3.21–3.08 (m, 1 H in CH_2), 2.61–2.46 (m, 1 H in CH_2), 2.41 (s, 3 H, CH_3), 2.35–2.23 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 197.8, 156.6, 144.4, 133.9, 129.44, 129.37, 128.7, 128.6, 128.2, 128.1, 68.7, 67.1, 53.2, 41.0, 35.3, 21.7.

HRMS (ESI): *m*/*z* calcd for$C_{20}H_{23}ClNO_5S^+$: 424.0980 $[M + H]^+$; found: 424.0991.

Benzyl [5-(4-Chlorophenyl)-2-chlorosulfonyl-5-oxopentyl]carbamate (4i)

Colorless oil; yield: 440 mg (71%).

IR (KBr): 3348, 2930, 1772, 1712, 1591, 1221, 1050 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.87 (d, *J* = 8.5 Hz, 2 H, ArH), 7.41 (d, *J* = 8.5 Hz, 2 H, ArH), 7.41–7.30 (m, 5 H, ArH), 5.28 (s, 2 H, CH_2), 5.24 (s, 1 H, NH), 4.22 (dd, *J* = 11.3, 6.9 Hz, 1 H in CH_2), 3.90 (dd, *J* = 11.3, 5.3 Hz, 1 H in CH_2), 3.79–3.72 (m, 1 H, CH), 3.16–2.99 (m, 2 H, CH_2), 2.30–2.26 (m, 1 H in CH_2), 2.15–2.04 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 196.9, 150.6, 140.0, 134.7, 129.4, 129.1, 128.7, 128.6, 128.3, 67.1, 53.2, 41.0, 35.3, 29.4, 21.7.

HRMS (ESI): *m*/*z* calcd for $C_{19}H_{20}Cl_2NO_5S^+$: 444.0434 $[M + H]^+$; found: 444.0441.

Benzyl [5-(4-Bromophenyl)-2-chlorosulfonyl-5-oxopentyl]carbamate (4j)

Colorless oil; yield: 409 mg (60%).

IR (KBr): 3346, 2935, 1774, 1710, 1595, 1519, 1224, 1049 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.82 (d, *J* = 8.4 Hz, 2 H, ArH), 7.62 (d, *J* = 8.5 Hz, 2 H, ArH), 7.31 (br s, 5 H, ArH), 5.47 (br s, 1 H, NH), 5.12 (s, 2 H, CH_2), 3.99–3.91 (m, 1 H, CH), 3.89–3.80 (m, 2 H, CH_2), 3.37–3.24 (m, 2 H, CH_2), 2.55 (td, *J* = 12.9, 6.6 Hz, 1 H in CH_2), 2.29–2.23 (m, 1 H in CH_2).

^{13}C NMR (101 MHz, $CDCl_3$): δ = 197.0, 156.4, 135.9, 134.9, 132.1, 129.6, 128.9, 128.6, 128.4, 128.1, 74.9, 67.4, 40.3, 34.5, 22.0.

HRMS (ESI): *m*/*z* calcd for $C_{19}H_{20}BrClNO_5S^+$: 487.9929 $[M + H]^+$; found: 487.9935.

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Supporting Information

Supporting information for this article is available online at http://dx.doi.org/10.1055/s-0036-1588706.

References

(1) Xu, J. X. *Chin. J. Org. Chem.* **2003**, *23*, 1.
(2) (a) Monnee, M. C. F.; Marijne, M. F.; Brouwer, A. J.; Liskamp, R. M. J. *Tetrahedron Lett.* **2000**, *41*, 7991. (b) He, F. D.; Meng, F. H.; Song, X. Q.; Hu, W. X.; Xu, J. X. *Org. Lett.* **2009**, *11*, 3922.
(3) Carson, K. G.; Schwender, C. F.; Shroff, H. N.; Cochran, N. A.; Gallant, D. L.; Briskin, J. M. *Bioorg. Med. Chem. Lett.* **1997**, *7*, 711.
(4) Moree, W. J.; van der Marel, G. A.; Liskamp, R. M. J. *Tetrahedron Lett.* **1991**, *32*, 409.
(5) Humljan, J.; Kotnik, M.; Boniface, A.; Solmajer, T.; Urleb, U.; Blanot, D.; Gobec, S. *Tetrahedron* **2006**, *62*, 10980.
(6) (a) Kakaei, S.; Xu, J. X. *Tetrahedron* **2013**, *69*, 9068. (b) Vertesaljai, P.; Biswas, S.; Lebedyeva, I.; Broggi, E.; Asiri, A. M.; Katritzky, A. R. *J. Org. Chem.* **2014**, *79*, 2688.
(7) (a) Marchand-Brynaert, J.; Bouchet, M.; Touillaux, R.; Beauve, C.; Fastrez, J. *Tetrahedron* **1996**, *52*, 5591. (b) Giordano, C.; Masi, A.; Pizzini, A.; Sansone, A.; Consalvi, V.; Chiaraluce, R.; Lucente, G. *Eur. J. Med. Chem.* **2009**, *44*, 179. (c) Brouwer, A. J.; Ceylan, T.; Jonker, A. M.; van der Linden, T.; Liskamp, R. M. J. *Bioorg. Med. Chem.* **2011**, *19*, 2397. (d) Uraguchi, D.; Kinoshita, N.; Nakashima, D.; Ooi, T. *Chem. Sci.* **2012**, *3*, 3161.
(8) Meng, F. H.; Chen, N.; Xu, J. X. *Sci. China Chem.* **2012**, *55*, 2548.
(9) (a) Gennari, C.; Ceccarelli, S.; Piarulli, U.; Montalbetti, C. A. G. N.; Jackson, R. F. W. *J. Org. Chem.* **1998**, *63*, 5312. (b) van Ameijde, J.; Liskamp, R. M. J. *Tetrahedron Lett.* **2000**, *41*, 1103. (c) Giordano, C.; Sansone, A.; Masi, A.; Lucente, G.; Punzi, P.; Mollica, A.; Pinnen, F.; Feliciani, F.; Cacciatore, I.; Davis, P.; Lai, J.; Ma, S. W.; Porreca, F.; Hruby, V. *Eur. J. Med. Chem.* **2010**, *45*, 4594.
(10) Chen, Z. L.; Demuth, T. P. Jr.; Wireko, F. C. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 2111.
(11) Bischofberger, N.; Waldmann, H.; Saito, T.; Simon, E. S.; Lees, W.; Bednarski, M. D.; Whitesides, G. M. *J. Org. Chem.* **1988**, *53*, 3457.
(12) (a) Bischoff, L.; David, C.; Roques, B. P.; Zaluski, M. C. F. *J. Org. Chem.* **1999**, *64*, 1420. (b) Lowik, D. W. P. M.; Liskamp, R. M. J. *Eur. J. Org. Chem.* **2000**, 1219.
(13) For recent related reviews, see: (a) Quiclet-Sire, B.; Zard, S. Z. *Synlett* **2016**, *27*, 680. (b) Debien, L.; Quiclet-Sire, B.; Zard, S. Z. *Acc. Chem. Res.* **2015**, *48*, 1237. (c) Quiclet-Sire, B.; Zard, S. Z. *Chem. Eur. J.* **2006**, *12*, 6002.
(14) (a) Yang, Z. H.; Xu, J. X. *Synthesis* **2013**, *45*, 1675. (b) Yang, Z. H.; Xu, J. X. *Org. Synth.* **2014**, *91*, 116.
(15) Prakash, G. K. S.; Mathew, T.; Panja, C.; Olah, G. A. *J. Org. Chem.* **2007**, *72*, 5847.
(16) (a) Bahrami, K.; Khodaei, M. M.; Soheilizad, M. *J. Org. Chem.* **2009**, *74*, 9287. (b) Bahrami, K.; Khodaei, M. M.; Soheilizad, M. *Synlett* **2009**, 2773.
(17) (a) Yang, Z. H.; Zheng, Y. P.; Xu, J. X. *Synlett* **2013**, *24*, 2165. (b) Yang, Z. H.; Zhou, B. N.; Xu, J. X. *Synthesis* **2014**, *46*, 225.
(18) (a) Xu, C. X.; Xu, J. X. *Amino Acids* **2011**, *41*, 195. (b) Chen, N.; Xu, J. X. *Tetrahedron* **2012**, *68*, 2513.
(19) (a) Ma, Y. H.; Xu, J. X. *Synthesis* **2012**, *44*, 2225. (b) Nai, Y. F.; Xu, J. X. *Helv. Chim. Acta* **2013**, *96*, 1355.
(20) (a) Douglass, I. B.; Johnson, T. B. *J. Am. Chem. Soc.* **1938**, *60*, 1486. (b) Douglass, I. B.; Osborne, C. E. *J. Am. Chem. Soc.* **1953**, *75*, 4582.
(21) Kakaei, S.; Chen, N.; Xu, J. X. *Tetrahedron* **2013**, *69*, 302.
(22) Joyard, Y.; Papamicaël, C.; Bohn, P.; Bischoff, L. *Org. Lett.* **2013**, *15*, 2294.