Supporting Information

for

Manganese/bipyridine-catalyzed non-directed C(sp³)–H bromination using NBS and TMSN₃

Kumar Sneh, Takeru Torigoe and Yoichiro Kuninobu

*Beilstein J. Org. Chem.* **2021**, *17*, 885–890. doi:10.3762/bjoc.17.74

Experimental procedures, compound characterization data, and copies of ¹H and ¹³C NMR spectra
# Table of Contents

1. General information                                      S2  
2. Structures of substrates                                S2  
3. Experimental section                                    S3  
   3-1. Preparation of substrates                            S3  
   3-2. Screening of reaction conditions                    S6  
   3-3. C(sp^3)–H bromination                              S8  
   3-4. Conversion of introduced bromine atom               S14  
4. References                                               S16  
5. $^1$H and $^{13}$C NMR spectra                           S17  

S1
1. **General information**

All reactions were carried out under nitrogen atmosphere unless otherwise noted. Toluene (anhydrous, Wako), dichloromethane (anhydrous, Wako), THF (anhydrous, Wako), ethyl acetate (anhydrous, Wako), and DMF (anhydrous, Wako) were used as received from commercial sources. MeCN and PhCF₃ was distilled over CaH₂ prior to use. Other reagents were purchased from commercial sources and used without further purification. $^1$H (400 MHz), $^{13}$C (100 MHz), and $^{19}$F (368 MHz) NMR spectra were recorded using a JEOL ECZ400 spectrometer. High resolution mass spectra were recorded on JEOL JMS-700 (EI) spectrometer.

2. **Structures of substrates**

![Chemical structures of substrates](image)
3. Experimental section

3-1. Preparation of substrates

Substrates 1h, 1i, and 1k are commercially available. Substrates 1a–g, 1j, 1l–o were prepared by following the literature procedure.1 Substrates 1a, 1c, 1e, 1n, and 1o are unknown compounds, and other substrates are known compounds. All other starting materials, solvents, and reagents were purchased and used as received.

General procedure 1:

\[
\text{R} \begin{array}{c}
\text{O} \\
\text{Cl}
\end{array} + \text{HO} \begin{array}{c}
\text{R} \\
\text{O} \\
\text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{3}
\end{array} \xrightarrow{\text{DMAP, Et}_{3}\text{N}} \text{DCM, 25 °C} \rightarrow \text{R} \begin{array}{c}
\text{O} \\
\text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{3}
\end{array}
\]

To a solution of alcohol (5.00 mmol, 1.0 equiv), DMAP (4-dimethylaminopyridine, 1.00 mmol, 0.20 equiv) and Et\textsubscript{3}N (1.00 mL, 7.50 mmol, 1.5 equiv) in DCM (25.0 mL) at 0 °C was added benzoyl chloride derivative (6.00 mmol, 1.2 equiv). The mixture was warmed to 25 °C and stirred for 6 h. The reaction mixture was quenched with H\textsubscript{2}O (5.0 mL) and extracted with DCM (3 × 10 mL). The combined organic layer was dried over MgSO\textsubscript{4}. The filtrate was concentrated in vacuo and the residue was purified by chromatography on silica gel (hexanes/EtOAc) to afford the desired benzoate.

General procedure 2:

\[
\text{R} \begin{array}{c}
\text{O} \\
\text{OH}
\end{array} + \text{HO} \begin{array}{c}
\text{R} \\
\text{O} \\
\text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{3}
\end{array} \xrightarrow{\text{EDCI, DMAP, Et}_{3}\text{N}} \text{DCM, 25 °C} \rightarrow \text{R} \begin{array}{c}
\text{O} \\
\text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{2} \text{CH}_{3}
\end{array}
\]

To a solution of benzoic acid derivative (7.00 mmol, 1.0 equiv), DMAP (4-dimethylaminopyridine) (1.40 mmol, 0.20 equiv) and Et\textsubscript{3}N (14.0 mmol, 2.0 equiv) in DCM (50.0 mL) at 25 °C were added EDCI (1-ethyl-(3-(3-dimethylamino)propyl)carbodiimide hydrochloride) (14.0 mmol, 2.00 equiv) and alcohol (7.00 mmol, 1.0 equiv). The mixture was
warmed to 25 °C and stirred for 6 h. The reaction mixture was quenched with H₂O (10 mL) and extracted with DCM (3 x 20 mL). The combined organic layer was dried over MgSO₄. The filtrate was concentrated in vacuo and the residue was purified by chromatography on silica gel (hexanes/EtOAc) to afford the desired benzoate.

**Isopentyl 4-(trifluoromethyl)benzoate (1a)**

Substrate 1a was synthesized according to general procedure 2; purified by column chromatography on silica gel (hexane/ethyl acetate = 50:1); colorless liquid (79% yield): ¹H NMR (400 MHz, CDCl₃) δ 8.14 (d, J = 8.0 Hz, 2H), 7.69 (d, J = 8.0 Hz, 2H), 4.39 (t, J = 6.6 Hz, 2H), 1.84-1.74 (m, 1H), 1.68 (td, J = 6.6, 6.6 Hz, 2H), 0.98 (d, J = 6.4 Hz, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 165.4, 134.3 (q, J = 32.6 Hz), 133.7, 129.9, 125.3 (q, J = 3.8 Hz), 123.6 (q, J = 271 Hz), 64.2, 37.3, 25.2, 22.5; ¹⁹F NMR (376 MHz, CDCl₃) δ -63.0; HRMS (ESI⁺) m/z: [M⁺] Calcd. For C₁₃H₁₆F₃O₂: 261.1102; Found 261.1101.

**Isopentyl 3-fluorobenzoate (1c)**

Substrate 1c was synthesized according to general procedure 1; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (75% yield): ¹H NMR (400 MHz, CDCl₃) δ 7.81 (ddd, J = 8.0, 1.6, 1.6 Hz, 1H), 7.69 (ddd, J = 9.2, 1.6, 1.6 Hz, 1H), 7.40 (ddd, J = 8.0, 8.0, 5.6 Hz, 1H), 7.23 (ddd, J = 8.0, 8.0, 3.2 Hz, 1H), 4.35 (t, J = 6.8 Hz, 2H), 1.83-1.73 (m, 1H), 1.65 (td, J = 6.8, 6.8 Hz, 2H), 0.96 (d, J = 6.4 Hz, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 165.5, 162.5 (d, J = 245 Hz), 132.6 (d, J = 7.7 Hz), 130.0 (d, J = 7.6 Hz), 125.2 (d, J = 2.9 Hz), 120.1 (d, J = 21.0 Hz), 116.4 (d, J = 23.0 Hz), 64.0, 37.3, 25.2, 22.5; ¹⁹F NMR (376 MHz, CDCl₃) δ -112.4; HRMS (ESI⁺) m/z: [M⁺] Calcd. For C₁₂H₁₆F₂O: 211.1134; Found 211.1134.
Isopentyl 3-bromobenzoate (1e)

Substrate 1e was synthesized according to general procedure 2; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (80% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.16 (dd, $J = 1.6$, 1.6 Hz, 1H), 7.96 (ddd, $J = 8.4$, 1.2, 1.2 Hz, 1H), 7.69-7.65 (m, 1H), 7.31 (dd, $J = 7.8$, 7.8 Hz, 1H), 4.36 (t, $J = 6.6$ Hz, 2H), 1.83-1.73 (m, 1H), 1.66 (td, $J = 6.9$, 6.6 Hz, 2H), 0.97 (d, $J = 6.4$ Hz, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 165.3, 135.7, 132.5, 132.4, 129.9, 128.1, 122.4, 64.1, 37.3, 25.2, 22.5; HRMS (ESI$^+$) m/z: [M$^+$] Calcd. For C$_{12}$H$_{15}$BrO$_2$, 270.0255; Found 270.0255.

4-Methylpentan-2-yl 4-(trifluoromethyl)benzoate (1n)

Substrate 1o was synthesized according to general procedure 2; purified by column chromatography on silica gel (hexane/ethyl acetate = 50:1); colorless liquid (84% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.15 (d, $J = 8.0$ Hz, 2H), 7.69 (d, $J = 8.0$ Hz, 2H), 5.31-5.23 (m, 1H), 1.77-1.67 (m, 2H), 1.46-1.38 (m, 1H), 1.35 (d, $J = 5.9$ Hz, 3H), 0.94 (d, $J = 6.4$ Hz, 3H), 0.93 (d, $J = 6.4$ Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 165.0, 134.2 (q, $J = 30.7$ Hz), 134.1, 129.9, 125.3 (q, $J = 3.8$ Hz), 123.7 (q, $J = 271$ Hz), 71.0, 45.1, 24.8, 22.9, 22.3, 20.5; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -63.0; HRMS (ESI$^+$) m/z: [M$^+$] Calcd. For C$_{14}$H$_{18}$F$_3$O$_2$: 275.1259; Found 275.1260.

Isopentyl 2-(4-fluorophenyl)acetate (1o)

Substrate 1p was synthesized according to general procedure 2; purified by column chromatography on silica gel (hexane/ethyl acetate = 10:1); colorless liquid (91% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.23 (dd, $J = 8.8$, 5.5 Hz, 2H), 6.99 (dd, $J = 8.8$, 8.8 Hz, 2H), 4.10 (t, $J = 6.9$ Hz, 2H), 3.57 (s, 2H), 1.68-1.58 (m, 1H), 1.49 (td, $J = 6.9$, 6.9 Hz, 2H), 0.88 (d, $J = 6.9$ Hz, 6H);
$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 171.5, 161.9 (d, $J = 244$ Hz), 130.8 (d, $J = 7.6$ Hz), 129.8 (d, $J = 3.8$ Hz), 115.3 (d, $J = 21.0$ Hz), 63.6, 40.5, 37.2, 25.0, 22.4; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -115.8; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. For C$_{13}$H$_{18}$FO$_2$: 225.1291; Found 225.1291.

3-2. Screening of reaction conditions

**Table S1.** Screening of several ligands$^a$

| Entry | Ligand     | Yield (%)$^b$ |
|-------|------------|---------------|
| 1     | bpy        | 62            |
| 2$^c$ | bpy        | 32            |
| 3     | dtbpy      | 50            |
| 4     | phen       | 65            |
| 5     | neocuproine| 51            |
| 6     | Me$_4$phen | 61            |
| 7     | terpyridine| 59            |

![Chemical Structures](image)

$^a$Conditions: 1a (0.100 mmol, 1.0 equiv), NBS (0.300 mmol, 3.0 equiv), Mn(OAc)$_2$ (10 mol %), ligand (10 mol %), TMSN$_3$ (0.200 mmol, 2.0 equiv), PhCF$_3$ (0.50 mL). $^b$H NMR yield was determined using 1,1,2,2-tetrachloroethane as an internal standard. $^c$Mixed solvent (PhCF$_3$/acetone = 4:1).
The yields obtained by bpy (Entry 1) and phen (Entry 4) were almost the same. Because bpy is cheaper than phen, we utilized bpy as the ligand.

Table S2. Screening of metal salts

![Chemical structure](image)

| Entry | MX<sub>n</sub> | Yield (%)<sup>b</sup> |
|-------|----------------|----------------------|
| 1     | Mn(TFA)<sub>2</sub> | 41                   |
| 2     | (MeCp)Mn(CO)<sub>3</sub> | 43                   |
| 3     | MnF<sub>3</sub> | 53                   |
| 4     | MnF<sub>3</sub>/phen | 54                   |
| 5     | Mn(acac)<sub>2</sub> | 54                   |
| 6     | MnBr<sub>2</sub> | 55                   |
| 7     | MnCl<sub>2</sub> | 41                   |
| 8     | Mn(OAc)<sub>3</sub> | 58                   |
| 9     | Mn(acac)<sub>3</sub> | 45                   |

<sup>a</sup>Conditions: 1a (0.100 mmol, 1.0 equiv), NBS (0.300 mmol, 3.0 equiv), metal salt (10 mol %), bpy (10 mol %), TMSN<sub>3</sub> (0.200 mmol, 2.0 equiv), PhCF<sub>3</sub> (0.50 mL). <sup>b</sup>H NMR yield was determined using 1,1,2,2-tetrachloroethane as an internal standard.
Table S3. Screening of halogen sources$^a$

![Reaction Scheme](attachment://reaction_scheme.png)

| Entry | Halogen Source | Yield (%)$^b$ |
|-------|----------------|--------------|
| 1     | NBS            | 62           |
| 2     | A              | 42           |
| 3     | B              | <1           |
| 4     | C              | <1           |
| 5     | D              | <1           |

$^a$Conditions: 1a (0.100 mmol, 1.0 equiv), brominating agent (0.300 mmol, 3.0 equiv), Mn(OAc)$_2$ (10 mol %), bpy (10 mol %), TMSN$_3$ (0.200 mmol, 2.0 equiv), PhCF$_3$ (0.50 mL). $^b$H NMR yield was determined using 1,1,2,2-tetrachloroethane as an internal standard.

3-3. C(sp$^3$)–H Bromination:

**General procedures for C(sp$^3$)–H bromination**

Substrate 1 (0.200 mmol), NBS (0.600 mmol, 31.2 mg), Mn(OAc)$_2$ (0.010 mmol, 2.3 mg), ligand (0.010 mmol, 2.7 mg) were added into a reaction vial (10 mL) with a magnetic stir bar under N$_2$ atmosphere. PhCF$_3$ (1.0 mL) was added and stirred for 5 min. Then, TMSN$_3$ was added and the vial was sealed with a cap. The reaction mixture was stirred at 60 °C for 18 h. The reaction mixture was cooled to room temperature and diluted with EtOAc. Then the mixture was filtered through a short celite pad and purified by column chromatography on silica gel using hexane/EtOAc mixtures as the eluent.
3-Bromo-3-methylbutyl 4-(trifluoromethyl)benzoate (2a)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (53% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) δ 8.15 (d, \(J = 8.2\) Hz, 2H), 7.71 (d, \(J = 8.2\) Hz, 2H), 4.62 (t, \(J = 6.8\) Hz, 2H), 2.32 (t, \(J = 6.8\) Hz, 2H), 1.86 (s, 6H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) δ 165.2, 134.5 (q, \(J = 32.6\) Hz), 133.3, 130.0, 125.4 (q, \(J = 2.9\) Hz), 123.6 (q, \(J = 272\) Hz), 63.7, 63.7, 45.3, 34.7; \(^{19}\)F NMR (376 MHz, CDCl\(_3\)) δ -63.0; HRMS (ESI\(^+\)) \(m/z\): [M\(^+\)] Calcd. for C\(_{13}\)H\(_{15}\)BrF\(_3\)O\(_2\), 339.0208; Found 339.0207.

3-Bromo-3-methylbutyl benzoate (2b)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (64% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) δ 8.04 (dd, \(J = 6.6, 1.6\) Hz, 2H), 7.56 (tt, \(J = 7.3, 1.5\) Hz, 1H), 7.46-7.42 (m, 2H), 4.58 (t, \(J = 6.6\) Hz, 2H), 2.31 (t, \(J = 6.6\) Hz, 2H), 1.86 (s, 6H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) δ 166.4, 133.0, 130.1, 129.5, 128.3, 64.2, 63.0, 45.4, 34.7; HRMS (ESI\(^+\)) \(m/z\): [M\(^+\)] Calcd. for C\(_{12}\)H\(_{16}\)BrO\(_2\), 271.0334; Found 271.0334.

3-Bromo-3-methylbutyl 3-fluorobenzoate (2c)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (59% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) δ 7.83 (ddd, \(J = 7.8, 1.4, 1.4\) Hz, 1H), 7.70 (ddd, \(J = 9.3, 1.4, 1.4\) Hz, 1H), 7.46-7.38 (m, 1H), 7.27 (ddd, \(J = 8.4, 8.4, 2.4\) Hz, 1H), 4.59 (t, \(J = 6.8\) Hz, 2H), 2.30 (t, \(J = 6.8\) Hz, 2H), 1.86 (s, 6H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) δ 166.4, 133.0, 130.1, 129.5, 128.3, 64.2, 63.0, 45.4, 34.7; HRMS (ESI\(^+\)) \(m/z\): [M\(^+\)] Calcd. for C\(_{12}\)H\(_{16}\)BrO\(_2\), 271.0334; Found 271.0334.
Hz, 2H), 1.86 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 165.3, 162.5 (d, $J = 245$ Hz), 132.2 (d, $J = 7.7$ Hz), 130.0 (d, $J = 7.6$ Hz), 125.3 (d, $J = 2.9$ Hz), 120.1 (d, $J = 21.1$ Hz), 116.4 (d, $J = 23.0$ Hz), 64.0, 63.5, 45.3, 34.7; $^{19}$F NMR (376 MHz, CDCl$_3$) δ -112.2; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. for C$_{12}$H$_{15}$BrFO$_2$, 289.0239; Found 289.0240.

3-Bromo-3-methylbutyl 2-chlorobenzoate (2d)

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (49% yield): $^1$H NMR (400 MHz, CDCl$_3$) δ 7.82 (dd, $J = 7.8$, 1.8 Hz, 1H), 7.48-7.39 (m, 2H), 7.34-7.32 (m, 1H), 4.60 (t, $J = 6.9$ Hz, 2H), 2.31 (t, $J = 6.9$ Hz, 2H), 1.85 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 165.6, 133.7, 132.6, 131.3, 131.1, 129.9, 126.6, 64.0, 63.7, 45.2, 34.7; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. for C$_{12}$H$_{15}$BrClO$_2$, 304.9944; Found 304.9943.

3-Bromo-3-methylbutyl 3-bromobenzoate (2e)

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (60% yield): $^1$H NMR (400 MHz, CDCl$_3$) δ 8.16 (dd, $J = 1.8$, 1.8 Hz, 1H), 7.96 (ddd, $J = 7.6$, 1.2, 1.2 Hz, 1H), 7.71-7.66 (m, 1H), 7.32 (dd, $J = 7.8$, 7.8 Hz, 1H), 4.59 (t, $J = 6.9$ Hz, 2H), 2.30 (t, $J = 6.9$ Hz, 2H), 1.85 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) δ 165.1, 136.0, 132.6, 132.0, 130.0, 128.1, 122.5, 63.9, 63.5, 45.3, 34.7; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. for C$_{12}$H$_{15}$Br$_2$O$_2$, 348.9439; Found 348.9439.
2-Bromo-2-methylpropyl benzoate (2f)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (46% yield): 

1H NMR (400 MHz, CDCl₃) δ 8.09 (dd, J = 8.2, 1.6 Hz, 2H), 7.59 (tt, J = 7.3, 1.6 Hz, 1H), 7.49-7.45 (m, 2H), 4.45 (s, 2H), 1.86 (s, 6H); 

13C NMR (100 MHz, CDCl₃) δ 165.9, 133.3, 129.7 (3C), 128.5, 73.3, 60.9, 31.0; 

HRMS (ESI⁺) m/z: [M⁺] Calcd. for C₁₁H₁₃BrO₂, 256.0099; Found 256.0100.

2-(2-Bromo-1,3-dioxolan-2-yl)ethyl benzoate (2g)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); colorless liquid (79% yield): 

1H NMR (400 MHz, CDCl₃) δ 8.02 (dd, J = 8.2, 1.6 Hz, 2H), 7.55 (tt, J = 7.3, 1.6 Hz, 1H), 7.45-7.41 (m, 2H), 4.61 (t, J = 6.4 Hz, 2H), 4.44 (t, J = 6.1 Hz, 2H), 3.50 (t, J = 6.1 Hz, 2H), 2.84 (t, J = 6.4 Hz, 2H); 

13C NMR (100 MHz, CDCl₃) δ 170.2, 166.2, 133.1, 129.8, 129.6, 128.3, 64.0, 60.1, 33.9, 28.4; 

HRMS (ESI⁺) m/z: [M⁺] Calcd. for C₁₂H₁₄BrO₄, 301.0075; Found 301.0076.

1-Bromoadamantane (2h)

Following the general procedure for the C(sp³)–H bromination; purified by column chromatography on silica gel (hexane); white solid (62% yield): 

1H NMR (400 MHz, CDCl₃) δ 2.37 (d, J = 3.2 Hz, 6H), 2.14-2.06 (m, 3H), 1.73 (t, J = 3.0 Hz, 6H); 

13C NMR (100 MHz, CDCl₃) δ 66.8, 49.3, 35.5, 32.6; 

HRMS (ESI⁺) m/z: [M⁺] Calcd. for C₁₀H₁₄Br 213.0279; Found 213.0278.
(1s,3s,5s,7s)-1,3-Dibromoadamantane (2h)\(^4\)

Following the general procedure for the C(sp\(^3\))–H Bromination with reaction time of only 45 min; purified by column chromatography on silica gel (hexane); white solid (62% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 2.87 (s, 2H), 2.34-2.25 (m, 10H), 1.70 (t, \(J = 2.5\) Hz, 2H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 62.1, 59.0, 56.8, 47.0, 44.9, 35.0, 33.5.

1-Bromo-3,5-dimethyladamantane (2i)\(^4\)

Following the general procedure for the C(sp\(^3\))–H Bromination; purified by column chromatography on silica gel (hexane); white solid (61% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 2.20-2.11 (m, 3H), 2.03 (d, \(J = 12.0\) Hz, 2H), 1.96 (d, \(J = 12.0\) Hz, 2H), 1.41 (d, \(J = 12.4\) Hz, 2H), 1.34 (d, \(J = 12.4\) Hz, 2H), 1.20 (s, 2H), 0.86 (s, 6H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 66.6, 55.2, 49.7, 47.6, 41.8, 35.5, 32.8, 29.8; HRMS (ESI) \(m/z\): [M\(^+\)] Calcd. for C\(_{12}\)H\(_{18}\)Br, 241.0592; Found 241.0591.

Methyl (1r,3s,5R,7S)-3-bromoadamantane-1-carboxylate (2j)\(^6\)

Following the general procedure for the C(sp\(^3\))–H Bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); white solid (62% yield): \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 3.66 (s, 3H), 2.47 (s, 2H), 2.34-2.26 (m, 4H), 2.20 (t, \(J = 2.7\) Hz, 2H), 1.90-1.86 (m, 4H), 1.69-1.65 (m, 2H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 175.9, 63.7, 51.9, 49.6, 48.1, 44.9, 37.1, 34.4, 31.7.
Methyl 2-bromo-2-phenylacetate (2k)$^7$

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1); pale yellow oil (61% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.30-7.24 (m, 2H), 7.14-7.06 (m, 3H), 5.36 (s, 1H), 3.79 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.8, 135.7, 129.3, 128.8, 128.6, 128.4, 127.2, 53.4, 46.5.

Methyl 2-bromo-2-(4-fluorophenyl)acetate (2l)$^7$

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel using (20:1 hexane/ethyl acetate; colorless oil (57% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.57-7.52 (m, 2H), 7.08-7.02 (m, 2H), 5.34 (s, 1H), 3.79 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.7, 163.0 (d, $J$ = 248 Hz), 131.6 (d, $J$ = 3.8 Hz), 130.6 (d, $J$ = 8.6 Hz), 115.8 (d, $J$ = 21.0 Hz), 53.4, 45.3; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -111.3.

Methyl 2-bromo-2-(4-bromophenyl)acetate (2m)$^7$

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel using (20:1 hexane/ethyl acetate; colorless oil (55% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.50 (d, $J$ = 8.8 Hz, 2H), 7.42 (d, $J$ = 8.8 Hz, 2H), 5.30 (s, 1H), 3.79 (s, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.4, 134.7, 132.0, 130.3, 123.6, 53.5, 45.3.
4-Bromo-4-methylpentan-2-yl 4-(trifluoromethyl)benzoate (2n)

\[
\text{CF}_3 \quad \text{O} \quad \text{O} \quad \text{Br}
\]

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.15 (d, $J = 8.2$ Hz, 2H), 7.71 (d, $J = 8.2$ Hz, 2H), 5.56-5.49 (m, 1H), 2.39 (dd, $J = 15.6$, 8.7 Hz, 1H), 2.22 (dd, $J = 15.6$, 2.3 Hz, 1H), 1.83 (s, 3H), 1.77 (s, 3H), 1.41 (d, $J = 6.4$ Hz, 3H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 164.6, 134.4 (q, $J = 32.6$ Hz), 133.6, 129.9, 125.4 (q, $J = 2.9$ Hz), 123.6 (q, $J = 271$ Hz), 70.8, 64.3, 52.6, 35.4, 33.8, 21.6; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -63.0; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. For C$_{14}$H$_{17}$BrF$_3$O$_2$: 353.0364; Found 353.0366.

3-Bromo-3-methylbutyl 2-(4-fluorophenyl)acetate (2o)

Following the general procedure for the C(sp$^3$)–H Bromination; purified by column chromatography on silica gel (hexane/ethyl acetate = 10:1); colorless oil (30% yield): $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.23 (dd, $J = 8.2$, 5.5 Hz, 2H), 7.01 (dd, $J = 8.5$, 8.2 Hz, 2H), 4.34 (t, $J = 6.9$ Hz, 2H), 3.59 (s, 2H), 2.13 (t, $J = 6.9$ Hz, 2H), 1.75 (s, 6H); $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 171.3, 162.0 (d, $J = 244$ Hz), 130.8 (d, $J = 7.6$ Hz), 129.5 (d, $J = 3.9$ Hz), 115.4 (d, $J = 22.0$ Hz), 64.1, 63.1, 45.1, 40.5, 34.6; $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -115.5; HRMS (ESI$^+$) $m/z$: [M$^+$] Calcd. for C$_{13}$H$_{17}$BrFO$_2$: 303.0396; Found 303.0395.

3-4. Conversion of introduced bromine atom

3-Fluoro-3-methylbutyl 4-(trifluoromethyl)benzoate (3)$^8$

\[
\text{CF}_3 \quad \text{O} \quad \text{O} \quad \text{F}
\]

3-Bromo-3-methylbutyl 4-(trifluoromethyl)benzoate (2a, 86.0 mg, 0.250 mmol) and Selectfluor (213 mg, 0.600 mmol) were added in a seal tube under argon atmosphere. Freshly distilled dry MeCN (2 mL) was then added. The reaction mixture was stirred at 25 °C for 12 h. Water (5 mL)
was added, and the reaction mixture was extracted with CH₂Cl₂ (3 × 10 mL). The organic phases were combined and dried over anhydrous Na₂SO₄. After the removal of solvent under reduced pressure, the crude product was purified by column chromatography on silica gel (hexane/ethyl acetate = 20:1) as the eluent to give 3 as a colorless oil. Yield: 61.1 mg (86%). ¹H NMR (400 MHz, CDCl₃) δ 8.14 (d, J = 8.2 Hz, 2H), 7.71 (d, J = 8.2 Hz, 2H), 4.52 (t, J = 6.6 Hz, 2H), 2.13 (dt, J = 13.3, 6.6 Hz, 2H), 1.45 (d, J = 21.5 Hz, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 165.4, 134.5 (q, J = 32.6 Hz), 133.5, 130.1 (q, J = 10.6 Hz), 125.5 (q, J = 3.8 Hz), 123.6 (q, J = 271 Hz), 94.2 (d, J = 166 Hz), 61.4 (d, J = 5.7 Hz), 39.8 (d, J = 32.6 Hz), 27.1 (d, J = 24.9 Hz); ¹⁹F NMR (376 MHz, CDCl₃) δ -63.0 (3F), -138.6 (1F).

3,3-Dimethylhex-5-en-1-yl 4-(trifluoromethyl)benzoate (4)⁹

3-Bromo-3-methylbutyl 4-(trifluoromethyl)benzoate (2a, 69.1 mg, 0.200 mmol) and allyltributylstannane (132 mg, 0.400 mmol) were added in a reaction tube under argon atmosphere. Then, dry toluene (0.5 mL) and AIBN (azobisisobutyronitrile, 5.0 mg, 15 mmol%) were added and reaction tube was sealed. The mixture was stirred at 80 °C for 8 h. Water (5 mL) was added, and the resulting mixture was extracted with CH₂Cl₂ (3 × 10 mL). The organic phases were combined and dried over anhydrous MgSO₄. After the removal of the solvent under reduced pressure, the crude product was purified by column chromatography on silica gel (hexane/ethyl acetate/ (40:1) as the eluent to give 4 as a colorless oil. Yield: 38.3 mg (64%). ¹H NMR (400 MHz, CDCl₃) δ 8.14 (d, J = 8.2 Hz, 2H), 7.70 (d, J = 8.2 Hz, 2H), 5.90-5.79 (m, 1H), 5.09-5.02 (m, 2H), 4.42 (t, J = 7.4 Hz, 2H), 2.04 (d, J = 7.3 Hz, 2H), 1.72 (t, J = 7.4 Hz, 2H), 0.98 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 165.4, 134.9, 134.3 (q, J = 32.6 Hz), 133.6, 129.9, 125.3 (q, J = 3.8 Hz), 123.6 (q, J = 272 Hz), 117.5, 62.9, 46.8, 39.5, 32.6, 27.1; ¹⁹F NMR (376 MHz, CDCl₃) δ -63.0; HRMS (ESI⁺) m/z: [M] Calcd. for C₁₆H₂₀F₃O₂, 301.1415; Found 301.1415.
4. References

1. Guo, S.; Zhang, X.; Tang, P. Angew. Chem. Int. Ed. 2015, 54, 4065-4069.
2. Wang, X.; Wang, S.; Xue, W.; Gong, H. J. Am. Chem. Soc. 2015, 137, 11562-11565.
3. Inomata, S.; Harada, Y.; Matsuoka, S.; Ishizone, T. Tetrahedron 2013, 69, 3238-3248.
4. Khusnutdinov, R. I.; Shchadneva, N. A.; Khisamova, L. F. Russ. J. Org. Chem. 2015, 51, 184-187.
5. Senchyk, G. A., Lysenko, A. B., Boldog, I., Rusanov, E. B., Chernega, A. N., Krautscheid, H., Domasevitch K. V. Dalton Trans. 2012, 41, 8675-8689.
6. Berndt, J.-P.; Engel, A.; Hrdina, R.; Dehnen, S.; Schreiner, P. R. Organometallics 2019, 38, 329-335.
7. Wang, H.; Sun, X.; Hu, M.; Zhang, X.; Xie, L.; Gu, S. Adv. Synth. Catal. 2020, 362, 3347-3351.
8. Chen, H.; Liu, Z.; Lv, Y.; Tan, X.; Shen, H.; Yu, H. Z.; Li, C. Angew. Chem. Int. Ed. 2017, 56, 15411-15415.
9. Keck, G. E.; Yates, J. B. J. Am. Chem. Soc. 1982, 104, 5829-5831.
5. $^1$H and $^{13}$C NMR spectra

![Chemical Structure](image)

$^1$H NMR

$^{13}$C NMR
$^1$H NMR

$^{13}$C NMR
$\text{Br}$

$2b$

$^1\text{H NMR}$

$^1\text{C NMR}$

S23
$^1$H NMR

$^{13}$C NMR
$\text{Br}$

$\text{2e}$

$^1\text{H NMR}$

$^1\text{C NMR}$

$\text{Br}$

$\text{O}$

$\text{H NMR}$

$\text{C NMR}$
\[ \text{1H NMR} \]

\[ \text{13C NMR} \]
$^1$H NMR

$^{13}$C NMR
$^{1}H$ NMR

$^{13}C$ NMR
$\text{Br} - 21' - \text{Br}$

$\text{H NMR}$

$\text{13C NMR}$
$\text{Br}_2\text{i}$

$^1\text{H NMR}$

$^13\text{C NMR}$
$^1$H NMR

$^{13}$C NMR
$^{1}H$ NMR

$^{13}C$ NMR
$\text{H NMR}$

$\text{C NMR}$
$^{1}H$ NMR

$^{13}C$ NMR
$^{1}H$ NMR

$^{13}C$ NMR
