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Graphical abstract

Electroreductive coupling of aromatic ketones, aldehydes, and aldimines with α,β-unsaturated esters: synthesis of 5-aryl-γ-butyrolactones and lactams

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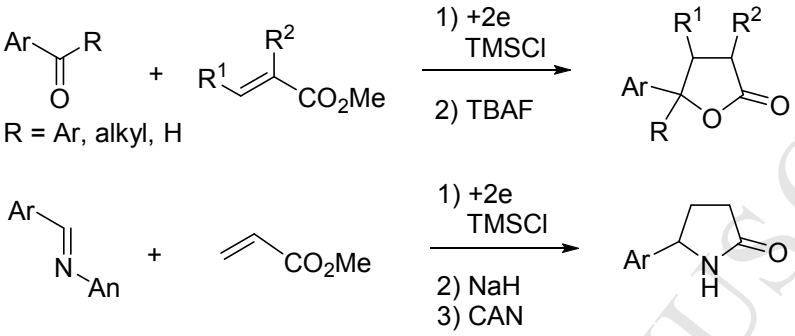

Electroreductive coupling of aromatic ketones, aldehydes, and aldimines with α,β-unsaturated esters: synthesis of 5-aryl substituted γ-butyrolactones and lactams

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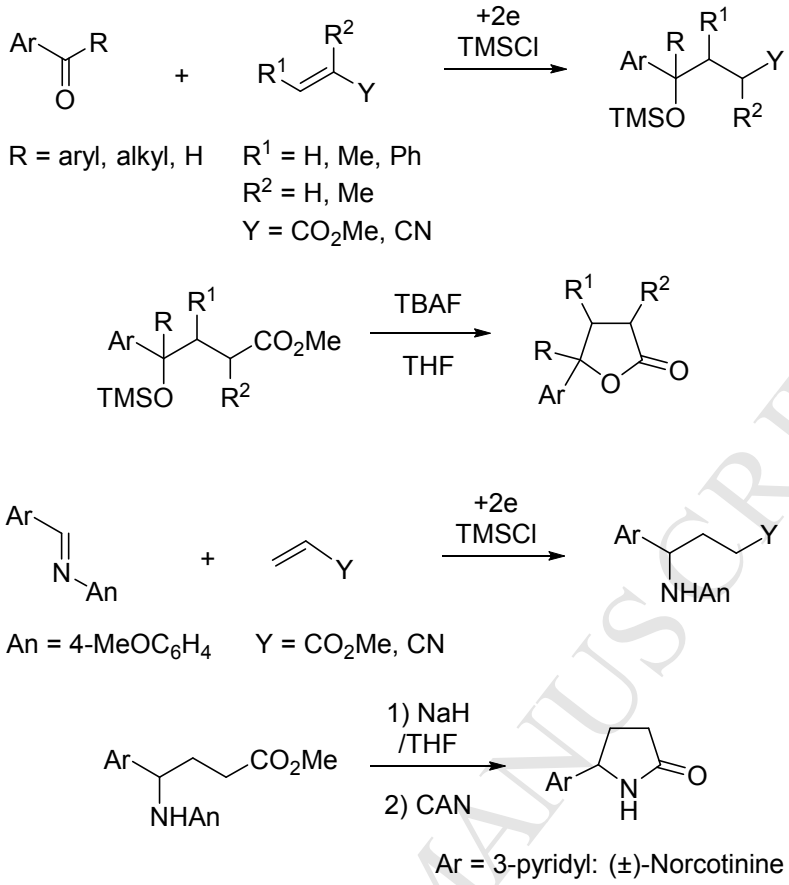
ABSTRACT

The electroreductive intermolecular coupling of aromatic ketones and aldehydes with α,β-unsaturated esters in the presence of TMSCl gave the adducts as γ-trimethylsiloxy esters. The detrimethylsilylation of the adducts with TBAF afforded 5-aryl substituted γ-butyrolactones. The electroreductive coupling of *N*-(4-methoxyphenyl)-1-arylmethaneimines with methyl acrylate in the presence of TMSCl gave the adducts as methyl 4-aryl-4-((4-methoxyphenyl)amino)butanoates. The adducts were transformed to 5-aryl-γ-butyrolactams by cyclization with NaH and subsequent oxidation with CAN. (±)-Norcotinine was prepared from nicotinaldehyde by this method. The electroreductive coupling of aromatic ketones and aldimines with acrylonitrile in the presence of TMSCl gave 4-aryl-4-(trimethylsiloxy)butanenitriles and 4-aryl-4-((4-methoxyphenyl)amino)butanenitriles, respectively.

Keywords: Reductive coupling; Electroreduction; Aromatic ketones; Aromatic aldimines; γ-Butyrolactones; γ-Butyrolactams

1. Introduction

In 1980, Shono and co-workers reported that the electroreductive cross-coupling of carbonyl compounds with α,β-unsaturated esters is a useful method for the synthesis of γ-butyrolactones.[1] After that, this type of reaction has also been realized with Zn[2] and SmI_2[3,4] as a reducing agent. In the first electroreductive intermolecular coupling[1] and the intramolecular coupling subsequently reported by Little and co-workers,[5] the employed carbonyl compounds were unfortunately limited to aliphatic ketones and aldehydes. Therefore, we attempted the inter- and intramolecular electroreductive coupling of aromatic carbonyl compounds with α,β-unsaturated esters to extend the scope of the electroreductive coupling. Meanwhile, we have already reported the preliminary results of the electroreductive coupling of aromatic aldimines with α,β-unsaturated esters.[6] Thereafter, the Ni-catalyzed reductive coupling of aldimines with activated alkenes was reported.[7] This paper prompted us to further investigate the scope of the electroreductive coupling of aromatic aldimines with α,β-unsaturated esters. We report in this paper the electroreductive coupling of aromatic ketones, aldehydes, and aldimines with α,β-unsaturated esters (Scheme 1). From the resultant γ-trimethylsiloxy and γ-amino esters (Y = CO_2Me), the corresponding 5-aryl substituted γ-butyrolactones and lactams were readily provided, respectively.[8] (±)-Norcotinine could be synthesized from nicotinaldehyde by this method. In addition, we report that the electroreductive coupling of aromatic ketones and aldimines with acrylonitrile (Y = CN) produced 4-aryl-4-(trimethylsiloxy)butanenitriles and 4-aryl-4-((4-methoxyphenyl)amino)butanenitriles (Scheme 1).



Scheme 1. Electroreductive coupling of aromatic ketones, aldehydes and aldimines with α,β-unsaturated esters and acrylonitrile.

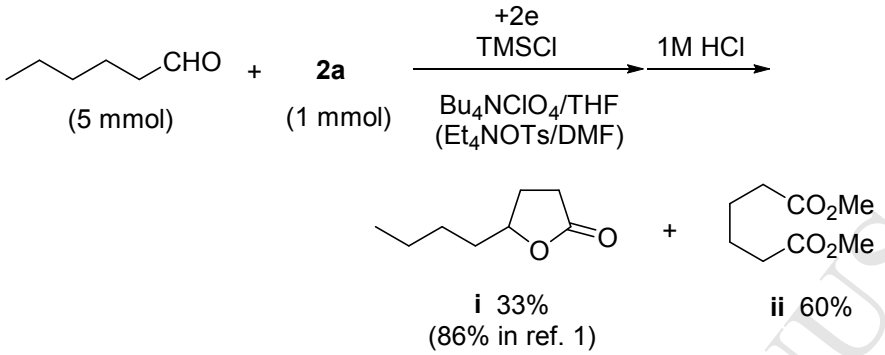
2. Results and discussion

2.1. Electroreductive coupling of aromatic ketones and aldehydes with α,β-unsaturated esters and nitriles.

In the previous report,[1] the electroreduction was carried out in Et_4NOTs/DMF in the presence of TMSCl. Under these conditions, aromatic ketones and aldehydes did not give any coupled product with α,β-unsaturated esters. On the other hand, we have already reported that the electroreductive coupling of aromatic ketones with *N*-acylimidazoles,[9a] aliphatic aldehydes and ketones,[9b] 3-methoxycarbonylindoles,[9c] 1-*E*-crotonyl- and 1-cinnnamoylimidazolidine-2-ones,[9d] and 1,3-dimethyluracils[9e,f] were effected in Bu_4NClO_4/THF or Bu_4NPF_6/THF in the presence of TMSCl. We therefore applied these conditions to the electroreduction of benzophenone (**1a**) with methyl acrylate (**2a**), and found that methyl 4,4-diphenyl-4-((trimethylsilyl)oxy)butanoate (**3a**) was obtained in almost the same yield (93-95%) under the both conditions. In addition, Pt, Au, Ag, Zn, and Pb gave almost the same results as a cathode material. Hence, we carried out the electroreduction of benzophenones **1a-g** with α,β-unsaturated esters **2a-d** (5 or 2 equiv) in Bu_4NClO_4/THF using a Pt cathode, and the results are summarized in Table 1. The adducts were obtained as TMS ethers **3a-g** by the reductive coupling of **1a-g** with **2a**, and subsequent detrimethylsilylation of **3a-g** with TBAF gave 5,5-diaryl-γ-butyrolactones **4a-g** (runs 1-7). Although the adducts **3h-v** obtained by the reactions with **2b-d** could not be purified, the corresponding γ-butyrolactones **4h-v** could be isolated after detrimethylsilylation of the crude **3h-v** (runs 8-22).

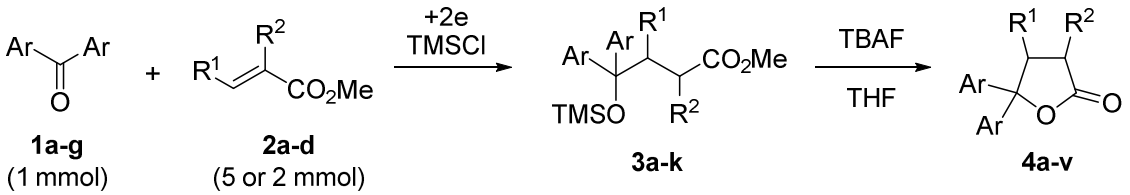
Similarly to our already reported reactions,[9] the presence of TMSCl is essential for the present electroreductive couplings. When the electroreduction of **1a** with **2a** was carried out in the absence of TMSCl, 1,1,2,2,-tetraphenylethane-1,2-diol was obtained as an only product by pinacol coupling of **1a**. This catholyte system (Bu_4NClO_4/THF) was employed to the electroreduction of hexanal with **2a** to compare with the previously reported catholyte system (Et_4NOTs/DMF).[1] As

shown in Scheme 2, the corresponding γ-butyrolactone **i** was obtained in 33% yield, and dimethyl adipate (**ii**) was formed as the major product (60% yield) by hydrodimerization of **2a**. Since it has been reported that the same γ-butyrolactone **i** was obtained in 86% yield,[1] these results show that Et_4NOTs/DMF is superior to Bu_4NClO_4/THF as the catholyte for the electroreductive coupling of aliphatic aldehydes with **2a**.



Scheme 2. Electroreduction of hexanal with 2a.

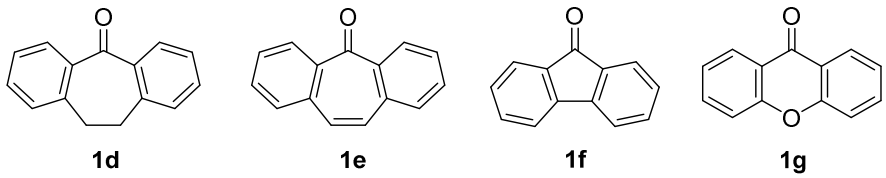
Table 1. Electroreductive coupling of 1a-g with 2a-d and transformation to 4a-v[a]



1a-g (1 mmol) **2a-d** (5 or 2 mmol) **3a-k** **4a-v**

run	**1**	$Ar_2C=O$	**2**	R^1	R^2	**3**	% yield[b]	**4**	% yield[b]
1	**1a**	Ar = Ph	**2a**[c]	H	H	**3a**	95	**4a**	90
2	**1b**	Ar = 4-$MeOC_6H_4$	**2a**[c]	H	H	**3b**	90	**4b**	85
3	**1c**	Ar = 4-FC_6H_4	**2a**[c]	H	H	**3c**	86	**4c**	80
4	**1d**	dibenzosuberone	**2a**[c]	H	H	**3d**	87	**4d**	69
5	**1e**	dibenzosuberenone	**2a**[c]	H	H	**3e**	84	**4e**	71
6	**1f**	9-fluorenone	**2a**[c]	H	H	**3f**	37	**4f**	32
7	**1g**	xanthone	**2a**[c]	H	H	**3g**	65	**4g**	57
8	**1a**	Ar = Ph	**2b**[c]	Me	H			**4h**	58
9	**1b**	Ar = 4-$MeOC_6H_4$	**2b**[c]	Me	H			**4i**	65
10	**1c**	Ar = 4-FC_6H_4	**2b**[c]	Me	H			**4j**	54
11	**1d**	dibenzosuberone	**2b**[c]	Me	H			**4k**	37
12	**1e**	dibenzosuberenone	**2b**[c]	Me	H			**4l**	38
13	**1g**	xanthone	**2b**[c]	Me	H			**4m**	30
14	**1a**	Ar = Ph	**2c**[c]	H	Me			**4n**	63
15	**1d**	dibenzosuberone	**2c**[c]	H	Me			**4o**	46
16	**1g**	xanthone	**2c**[c]	H	Me			**4p**	51
17	**1a**	Ar = Ph	**2d**[d]	Ph	H			**4q**	53
18	**1b**	Ar = 4-$MeOC_6H_4$	**2d**[d]	Ph	H			**4r**	25
19	**1c**	Ar = 4-FC_6H_4	**2d**[d]	Ph	H			**4s**	48
20	**1d**	dibenzosuberone	**2d**[d]	Ph	H			**4t**	47
21	**1e**	dibenzosuberenone	**2d**[d]	Ph	H			**4u**	58
22	**1g**	xanthone	**2d**[d]	Ph	H			**4v**	36

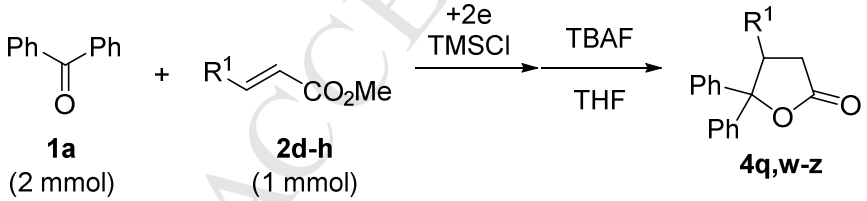
[a]The electroreduction of **1** (1 mmol) and **2** (5 or 2 mmol) in Bu_4NClO_4/THF using a Pt cathode at a constant current of 200 mA (200 C). [b]Isolated yields based on **1**. [c]5 mmol. [d]2 mmol.



1d **1e** **1f** **1g**

The electroreduction of **1a** with methyl cinnamates **2d-h** was carried out with the molar ratio of **1a**/**2d-h** as 2/1, since **2d-h** are more expensive than **1a** (Table 2). After desilylation of the crude adduct **3q**, the yield of **4q** was improved to 75% (run 1) in comparison to 53% yield of run 17 in Table 1. As shown in Table 3, aryl alkyl ketones **1h-n** (runs 1-9) and aromatic aldehydes **1o-s** (runs 10-14) were employed in place of benzophenones **1a-g**. The reaction of acetophenone (**1h**) with 2a gave the product **5a** in 78% yield, and subsequent desilylation of **5a** afforded 5-phenyl-5methyl-γ-butyrolactone (**6a**) in 96% yield (run 1). Although the adducts **5b,c** obtained by the reactions of **1h** with **2b,c** could not be purified, the corresponding γ-butyrolactones **6b** (63%) and **6c** (69%) could be isolated as mixtures of two diastereomers (50:50 dr) after treatment of the crude **2b,c** with TBAF (runs 2 and 3). Other acetophenones **1i-k** (runs 4-6) and phenyl alkyl ketones **1l-n** (runs 7-9) also applicable to the electroreductive coupling with **2a**, and the corresponding 5-aryl-5-methyl-γ-butyrolactones **6d-f** and 5-phenyl-5-alkyl-γ-butyrolactones **6g-i** were obtained by desilylation of the adducts **5d-f** and **5g-i**, respectively. Although the yields were lowered (35-56%), aromatic aldehydes **1o-s** were reacted with **2a** to give **5j-n** (runs 10-14). Desilylation of **5j-n** produced 5-aryl-γ-butyrolactones **6j-n** in high yields.

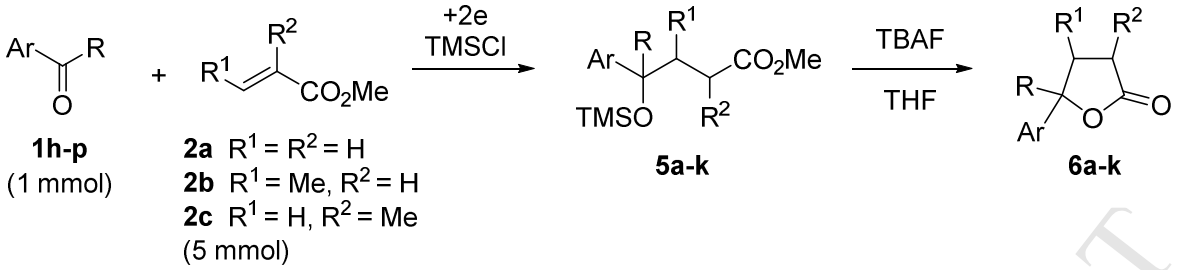
Table 2. Electroreductive coupling of 1a with 2d-h and transformation to 4q,w-z



run	**2**	R^1	**4**	% yield[a]
1	**2d**	Ph	**4q**	75
2	**2e**	4-$MeOC_6H_4$	**4w**	71
3	**2f**	4-FC_6H_4	**4x**	73
4	**2g**	3,4-methylenedioxyphenyl	**4y**	73
5	**2h**	2-naphthyl	**4z**	63

[a]Isolated yields based on **2**.

Table 3. Electroreductive coupling of 1h-p with 2a-c and transformation to 6a-k

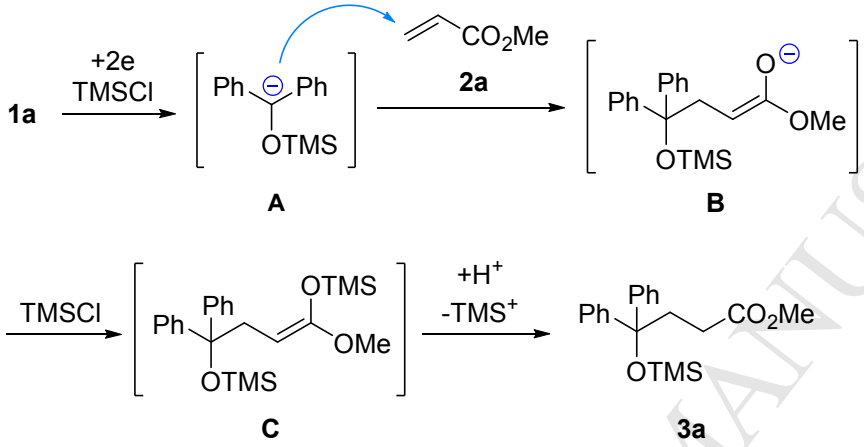


run	**1**	Ar	R	**2**	**5**	% yield[a]	**6**	% yield[b] (dr)[c]
1	**1h**	Ph	Me	**2a**	**5a**	78	**6a**	96
2	**1h**	Ph	Me	**2b**			**6b**	63[a] (50:50)
3	**1h**	Ph	Me	**2c**			**6c**	69[a] (50:50)
4	**1i**	4-$MeOC_6H_4$	Me	**2a**	**5d**	63	**6d**	90
5	**1j**	4-FC_6H_4	Me	**2a**	**5e**	85	**6e**	92
6	**1k**	2-naphthyl	Me	**2a**	**5f**	82	**6f**	96
7	**1l**	Ph	Et	**2a**	**5g**	87	**6g**	93
8	**1m**	Ph	*n*-Pr	**2a**	**5h**	89	**6h**	91
9	**1n**	Ph	*i*-Pr	**2a**	**5i**	93	**6i**	92
10	**1o**	Ph	H	**2a**	**5j**	49	**6j**	92
11	**1p**	4-$MeOC_6H_4$	H	**2a**	**5k**	56	**6k**	91
12	**1q**	4-FC_6H_4	H	**2a**	**5l**	35	**6l**	89
13	**1r**	3,4-methylenedioxyphenyl	H	**2a**	**5m**	50	**6m**	94
14	**1s**	2-naphthyl	H	**2a**	**5n**	45	**6n**	95

[a]Isolated yields based on **1**. [b]Isolated yields based on **5**. [c]Diastereomeric ratio.

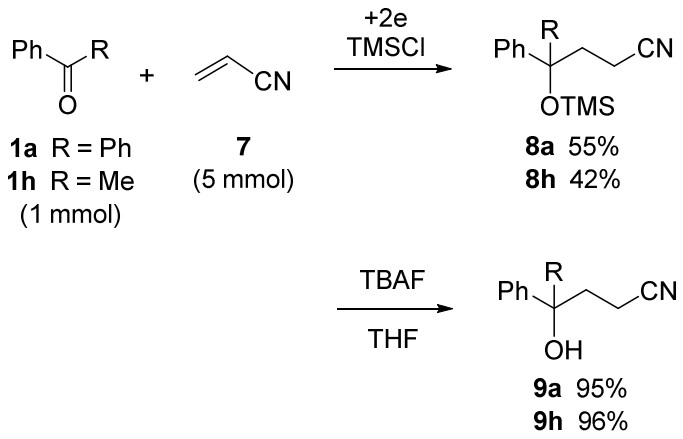
In the previous report,[1] it is presumed that the electroreductive coupling is initiated by the electron transfer to methyl acrylate (**2a**), since **2a** is more reducible than aliphatic carbonyl compounds. We measured the cyclic voltammetry (CV) of **1a**, **1h**, **1l**, and **2a** (3 mM) in 0.03 M Bu_4NClO_4/DMF on a platinum cathode. The first reduction peaks of their CV data showed that **1a** (−1.85 V vs SCE), **1h** (−2.10 V vs SCE), and **1l** (−1.94 V vs SCE) were more reducible than **2a**, since the CV data of **2a** gave no reduction peak from 0 to −2.20 V vs SCE. These results suggest that the electroreductive coupling of aromatic carbonyl compounds **1a**, **1h**, and **1l** with **2a** is

initiated by the electron transfer to **1a**, **1h**, and **1ly**. Hence, the presumed reaction mechanism of the electroreductive coupling of **1a** with **2a** can be illustrated as Scheme 3. As previously reported,[9] carbanion **A** is formed by the two-electron transfer to **1a** and *O*-silylation with TMSCl. The successive nucleophilic 1,4-addition of **A** to **2a** and *O*-silylation of the resultant enolate anion **B** produce silyl ketene acetal **C**. Finally, the labile **C** is readily desilylated to **3a** during workup.



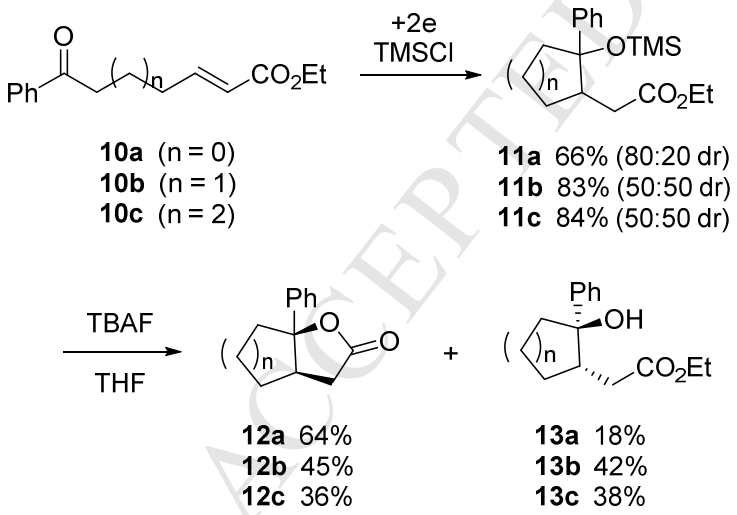
Scheme 3. Presumed reaction mechanism of electroreductive coupling of 1a with 2a.

Next, to expand the scope of the electroreductive coupling of aromatic ketones with α,β-unsaturated carbonyl compounds, acrylonitrile (**7**) was employed in place of methyl acrylate **2a**. The electroreduction of **1a,h** with **7** under the same conditions as described above also gave the adducts as 4-trimethylsiloxybutanenitriles **8a,h**, although the yields of **8a,h** were moderate (Scheme 4). The desilylation of **8a,h** by treatment with TBAF afforded 4-hydroxybutanenitriles **9a,h**.



Scheme 4. Electroreductive coupling of 1a,h with 7 and desilylation of 8a,h.

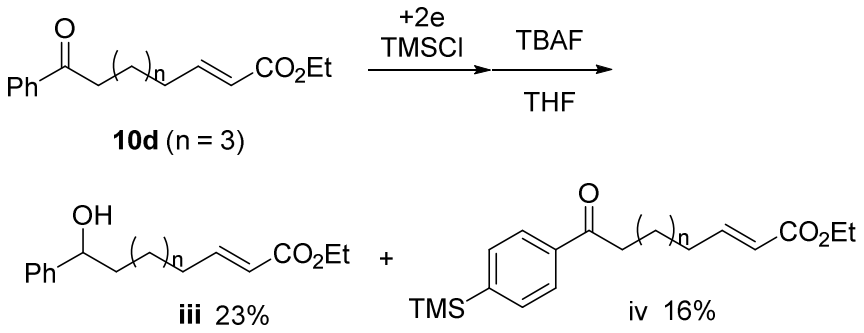
The electroreductive intramolecular coupling of ω-keto-α,β-unsaturated esters **10a-c** (n = 0~2) were also effected under the same conditions, although the four-, five-, and six-membered cyclized products **11a-c** were obtained as diastereomeric mixtures (Scheme 5). The desilylation of **11a-c** with TBAF gave *cis*-γ-butyrolactones **12a-c** and *trans*-γ-hydroxy esters **13a-c**.



Scheme 5. Electroreductive intramolecular coupling of 10a-c and desilylation of 11a-c.

Unfortunately, the electroreduction of **10d** (n = 3) and subsequent desilylation with TBAF gave complex mixture. From the mixture, simply reduced alcohol **iii** and 4-(trimethylsilyl)phenyl analog of **10d** (**iv**) were isolated, although intramolecularly coupled products **12d** and **13d** could not

be detected (Scheme 6).



Scheme 6. Electroreduction of 10d.

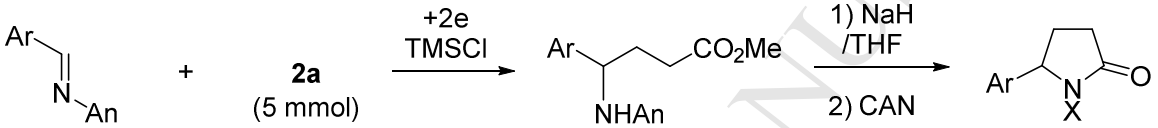
2.2. Electroreductive coupling of aromatic aldimines with methyl acrylate and acetonitrile.

In the preliminary report,[6] we disclosed that the electroreduction of *N*-(4-methoxyphenyl)-1-phenylmethanimine (**14a**) and 1-(4-chlorophenyl)-*N*-(4-methoxyphenyl)methanimine (**14b**) with **2a** in Et_4NOTs/DMF in the presence of TMSCl gave the adduct **15a** and **15b** in 63% and 65% yields, respectively (Table 4, runs 1 and 2). We have also revealed that the electroreductive coupling of **14a** with *N*-acetylimidazole gave the adduct in slightly higher yields under the conditions in Bu_4NClO_4/THF and Bu_4NPF_6/THF than those in Et_4NOTs/DMF.[10] Although the electroreduction of **14a** with **2a** was carried out in Bu_4NClO_4/THF and Bu_4NPF_6/THF, the yield of **15a** decreased to some extent (58% and 55%, respectively). Therefore, the electroreduction of the other aromatic aldimines **14c-j** with **2a** was performed in Et_4NOTs/DMF and the adducts **15c-j** were obtained in moderate to good yields (Table 4, runs 3-10). The cyclization of **15a-j** by treatment with NaH in THF gave 5-aryl-*N*-(4-methoxyphenyl)-γ-butyrolactams **16a-j** and then the *N*-4-methoxyphenyl group (An) in **16a-j** was removed by treatment with CAN in aqueous acetonitrile to give 5-aryl-γ-butyrolactams **17a-j**. From **14j** (Ar = 3-pyridyl) derived from nicotinaldehyde, (±)-norcotinine (**17j**) was synthesized in three steps (run 10). The An group in the adducts **15a-h** could be removed by treatment with CAN, and subsequent *N*-protection of the resultant methyl 4-aryl-4-aminobutyrates

with $(Boc)_2O$ gave methyl 4-aryl-4-((*t*-butoxycarbonyl)amino)butyrates **18a-h** (Table 5). These procedures provide a convenient method for the synthesis of γ-aryl substituted γ-amino acid (GABA) derivatives.

Similarly, the electroreduction of **14a-h** with **7** in Et_4NOTs/DMF in the presence of TMSCl afforded 4-aryl-4-((4-methoxyphenyl)amino)butanenitriles **19a-h** (Table 6). The adducts **19a-h** were converted to 4-aryl-4-((*t*-butoxycarbonyl)amino)butanenitriles **20a-h** by the same method as described above.

Table 4. Electroreductive coupling of 14a-j with 2a and transformation to 16a-j and 17a-j



14a-j An = 4-$MeOC_6H_4$ (1 mmol)

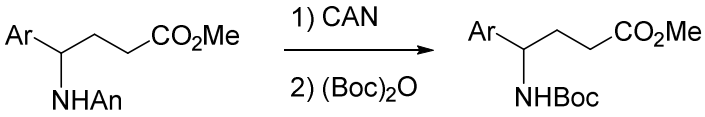
15a-j

16a-j X = An
17a-j X = H

run	**14**	Ar	**15**	% yield[a]	**16**	% yield[b]	**17**	% yield[c]
1	**14a**	Ph	**15a**	63	**16a**	90	**17a**	78
2	**14b**	4-ClC_6H_4	**15b**	65	**16b**	86	**17b**	79
3	**14c**	4-$MeOC_6H_4$	**15c**	51	**16c**	81	**17c**	65
4	**14d**	2-$MeOC_6H_4$	**15d**	65	**16d**	90	**17d**	72
5	**14e**	4-FC_6H_4	**15e**	60	**16e**	89	**17e**	70
6	**14f**	4-NCC_6H_4	**15f**	45	**16f**	80	**17f**	78
7	**14g**	1-naphthyl	**15g**	80	**16g**	86	**17g**	80
8	**14h**	2-naphthyl	**15h**	74	**16h**	80	**17h**	72
9	**14i**	3,4-$(MeO)_2C_6H_3$	**15i**	63	**16i**	84	**17i**	63
10	**14j**	3-pyridyl	**15j**	53	**16j**	80	**17j**	52

[a]Isolated yields based on **14**. [b]Isolated yields based on **15**. [c]Isolated yields based on **16**.

Table 5. Transformation of 15a-h to 18a-h

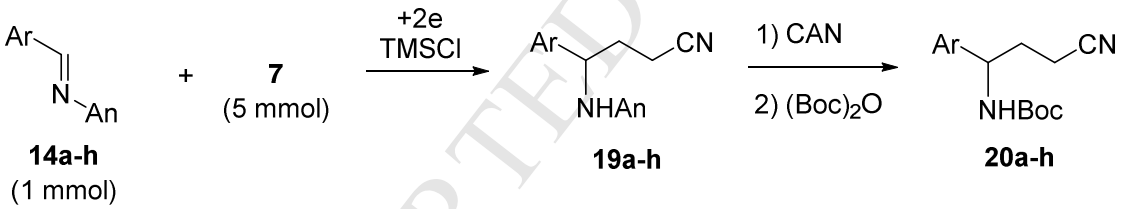


15a-h **18a-h**

run	**15**	Ar	**18**	% yield[a]
1	**15a**	Ph	**18a**	70
2	**15b**	4-ClC_6H_4	**18b**	71
3	**15c**	4-$MeOC_6H_4$	**18c**	58
4	**15d**	2-$MeOC_6H_4$	**18d**	53
5	**15e**	4-FC_6H_4	**18e**	67
6	**15f**	4-NCC_6H_4	**18f**	63
7	**15g**	1-naphthyl	**18g**	62
8	**15h**	2-naphthyl	**18h**	65

[a]Isolated yields based on **15**.

Table 6. Electroreductive coupling of 14a-h with 7 and transformation to 20a-h



14a-h (1 mmol) **19a-h** **20a-h**

run	**14**	Ar	**19**	% yield[a]	**20**	% yield[b]
1	**14a**	Ph	**19a**	68	**20a**	85
2	**14b**	4-ClC_6H_4	**19b**	63	**20b**	86
3	**14c**	4-$MeOC_6H_4$	**19c**	51	**20c**	81
4	**14d**	2-$MeOC_6H_4$	**19d**	65	**20d**	90
5	**14e**	4-FC_6H_4	**19e**	60	**20e**	89
6	**14f**	4-NCC_6H_4	**19f**	45	**20f**	80
7	**14g**	1-naphthyl	**19g**	80	**20g**	86
8	**14h**	2-naphthyl	**19h**	74	**20h**	80

[a]Isolated yields based on **14**. [b]Isolated yields based on **19**.

3. Conclusion

The electroreductive intermolecular coupling of aromatic ketones **1a-n** and aldehydes **1o-s** with α,β-unsaturated esters **2a-h** in the presence of TMSCl in Bu_4NClO_4/THF gave the adducts as 5-aryl substituted γ-trimethylsiloxy esters **3a-z** and **5a-n**. The adducts **3a-z** and **5a-n** were transformed to the corresponding γ-butyrolactones **4a-z** and **6a-n** by treatment with TBAF. The electroreductive coupling of aromatic ketones **1a** and **1h** with acrylonitrile (**7**) afforded 4-(trimethylsiloxy)butanenitriles **8a** and **8h**. The electroreductive intramolecular coupling of aromatic ketones with α,β-unsaturated esters was also effected and four-, five-, and six-membered cyclized products **11a-c** were produced from ω-keto-α,β-unsaturated esters **10a-c**, respectively. The electroreductive coupling of *N*-(4-methoxyphenyl)-1-arylmethaneimines **14a-j** with methyl acrylate (**2a**) in the presence of TMSCl in Et_4NOTs/DMF gave methyl 4-aryl-4-((4-methoxyphenyl)amino)butanoates **15a-j**. The adducts **15a-j** were transformed to 5-aryl-γ-butyrolactams **17a-j** by cyclization with NaH and subsequent *N*-deprotection of the resultant 5-aryl-*N*-(4-methoxyphenyl)-γ-butyrolactams **16a-j** with CAN. (±)-Norcotinine (**17j**) was prepared from nicotinaldehyde by this method. The electroreductive coupling of **14a-h** with **7** afforded 4-aryl-4-((4-methoxyphenyl)amino)butanenitriles **19a-h**. The adducts **15a-h** and **19a-h** were transformed to methyl 4-aryl-4-((t-butoxycarbonyl)amino)butyrates **18a-h** and 4-aryl-4-((*t*-butoxycarbonyl)amino)butanenitriles **20a-h**, respectively, by treatment with CAN and subsequent *N*-protection with $(Boc)_2O$.

4. Experimental section

4.1. General

THF was freshly distilled from sodium benzophenone ketyl radical. DMF, TMSCl, and TEA were distilled from CaH_2. Column chromatography was performed on silica gel 60. ^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra were measured on a JEOL JNM-ECP500 spectrometer with tetramethylsilane (TMS) as an internal standard. IR spectra were recorded on a Shimadzu IRAffinity-1 infrared spectrometer. HRMS were measured on a Thermo Scientic Exactive FTMS spectrometer. Melting points were uncorrected. Compound **10a-d** were prepared according to the reported method.[11]

4.2. Typical procedure of electroreductive coupling of 1 with 2

A 0.3 M solution of Bu_4NClO_4 in THF (15 mL) was placed in the cathodic chamber of a divided cell (40 mL beaker, 3 cm diameter, 6 cm height) equipped with a platinum cathode (5 X 5 cm^2), a platinum anode (2 X 1 cm^2), and a ceramic cylindrical diaphragm (1.5 cm diameter). A 0.3 M solution of Et_4NOTs in DMF (4 mL) was placed in the anodic chamber (inside the diaphragm). Benzophenone (**1a**) (182 mg, 1.0 mmol), methyl acrylate (**2a**) (0.45 mL, 5.0 mmol), TMSCl (0.64 mL, 5.0 mmol), and TEA (0.70 mL, 5.0 mmol) were added to the cathodic chamber. After 300 C (3 *F*/mol for **1a**) of electricity was passed at a constant current of 200 mA at 25 ºC under nitrogen atmosphere, the catholyte was evaporated in vacuo. The residue was dissolved in diethyl ether (20 mL) and insoluble solid was filtered off. After removal of the solvent in vacuo, the residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **3a** (325 mg) in 95% yield.

*4.2.1. Methyl 4,4-diphenyl-4-((trimethylsilyl)oxy)butanoate (**3a**)*: Colorless paste; *Rf* 0.65 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ −0.10 (s, 9H), 2.16-2.20 (m, 2H), 2.64-2.69 (m, 2H), 3.61 (s, 3H), 7.18-7.22 (m, 2H), 7.24-7.28 (m, 4H), 7.30-7.33 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 1.6 (q), 28.8 (t), 35.9 (t), 51.3 (q), 79.8 (s), 126.7 (d), 127.7 (d), 146.8 (s), 174.1

(s); HRMS (ESI) calcd for $C_{20}H_{27}O_3Si$ ($M + H^+$) 343.1729; found 343.1727.

*4.2.2. Methyl 4,4-bis(4-methoxyphenyl)-4-((trimethylsilyl)oxy)butanoate (**3b**)*: Colorless paste; *Rf* 0.35 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.11 (s, 9H), 2.15-2.20 (m, 2H), 2.57-2.62 (m, 2H), 3.61 (s, 3H), 3.79 (s, 6H), 6.77-6.81 (m, 4H), 7.20-7.24 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 1.4 (q), 28.7 (t), 36.1 (t), 51.0 (q), 54.7 (q), 79.1 (s), 112.7 (d), 127.7 (d), 139.0 (s), 158.1 (s), 174.0 (s); HRMS (ESI) calcd for $C_{22}H_{31}O_5Si$ ($M + H^+$) 403.1941; found 403.1938.

*4.2.3. Methyl 4,4-bis(4-fluorophenyl)-4-((trimethylsilyl)oxy)butanoate (**3c**)*: Colorless paste; *Rf* 0.55 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.09 (s, 9H), 2.14-2.18 (m, 2H), 2.59-2.64 (m, 2H), 3.61 (s, 3H), 6.93-6.99 (m, 4H), 7.24-7.29 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 1.5 (q), 28.7 (t), 36.0 (t), 51.3 (q), 79.1 (s), 114.6 (d, J_{CCF}=21.3 Hz), 128.4 (d, J_{CCCF}=7.5 Hz), 142.5 (s, J_{CCCCF}=3.6 Hz), 161.6 (s, J_{CF}=246.2 Hz), 173.9 (s); HRMS (ESI) calcd for $C_{20}H_{25}F_2O_3Si$ ($M + H^+$) 379.1541; found 379.1538.

*4.2.4. Methyl 3-(5-((trimethylsilyl)oxy)-10,11-dihydro-5H-dibenzo[a,d][7]annulen-5-yl)propanoate (**3d**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.13 (s, 9H), 2.13 (t, 2H, *J*=8.0 Hz), 2.49 (t, 2H, *J*=8.0 Hz), 2.98-3.13 (m, 4H), 3.57 (s, 3H), 7.04-7.07 (m, 2H), 7.14-7.18 (m, 2H), 7.21-7.25 (m, 2H), 7.77-7.81 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 1.8 (q), 29.5 (t), 35.9 (t), 43.6 (t), 51.2 (q), 83.3 (s), 125.7 (d), 127.1 (d), 129.6 (d), 130.3 (d), 140.2 (s), 143.7 (s), 173.9 (s); HRMS (ESI) calcd for $C_{22}H_{29}O_3Si$ ($M + H^+$) 369.1886; found 369.1884.

*4.2.5. Methyl 3-(5-((trimethylsilyl)oxy)-5H-dibenzo[a,d][7]annulen-5-yl)propanoate (**3e**)*: Colorless paste; *Rf* 0.4 (hexanes-ethyl acetate, 10:1); IR (ATR) 1734 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.36 (s, 9H), 1.80-1.85 (m, 2H), 2.36-2.42 (m, 2H), 3.53 (s, 3H), 7.03 (s, 2H), 7.21-7.25 (m, 2H), 7.29-7.33 (m, 2H), 7.36-7.42 (m, 2H), 7.80-7.84 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 2.8 (q), 29.5 (t), 30.2 (t), 51.2 (q), 81.5 (s), 124.7 (d), 126.2 (d), 128.3 (d), 128.9 (d), 131.5 (d), 131.9 (s), 142.0 (s), 173.3 (s); HRMS

(ESI) calcd for $C_{22}H_{27}O_3Si$ ($M + H^+$) 367.1729; found 367.1727.

*4.2.6. Methyl 3-(9-((trimethylsilyl)oxy)-9H-fluoren-9-yl)propanoate (**3f**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.36 (s, 9H), 2.04-2.08 (m, 2H), 2.36-2.40 (m, 2H), 3.54 (s, 3H), 7.26-7.30 (m, 2H), 7.34-7.37 (m, 2H), 7.46-7.48 (m, 2H), 7.60-7.62 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 1.2 (q), 29.1 (t), 37.1 (t), 51.3 (q), 83.1 (s), 119.9 (d), 124.3 (d), 127.6 (d), 128.8 (d), 139.5 (s), 148.1 (s), 173.8 (s); HRMS (ESI) calcd for $C_{20}H_{25}O_3Si$ ($M + H^+$) 341.1573; found 341.1572.

*4.2.7. Methyl 3-(9-((trimethylsilyl)oxy)-9H-xanthen-9-yl)propanoate (**3g**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.29 (s, 9H), 1.80-1.84 (m, 2H), 2.45-2.49 (m, 2H), 3.47 (s, 3H), 7.06-7.09 (m, 2H), 7.12-7.16 (m, 2H), 7.28-7.32 (m, 2H), 7.59-7.62 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 1.3 (q), 29.5 (t), 43.2 (t), 51.2 (q), 70.4 (s), 116.0 (d), 123.1 (d), 124.8 (s), 127.7 (d), 129.0 (d), 149.8 (s), 173.1 (s); HRMS (ESI) calcd for $C_{20}H_{25}O_4Si$ ($M + H^+$) 357.1522; found 357.1520.

*4.2.8. Methyl 4-phenyl-4-((trimethylsilyl)oxy)pentanoate (**5a**)*: Colorless paste; *Rf* 0.55 (hexanes-ethyl acetate, 10:1); IR (ATR) 1738 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.13 (s, 9H), 1.64 (s, 3H), 1.99-2.11 (m, 3H), 2.27-2.35 (m, 1H), 3.59 (s, 3H), 7.18-7.23 (m, 1H), 7.28-7.33 (m, 2H), 7.34-7.38 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 29.2 (t), 29.8 (q), 40.4 (t), 51.3 (q), 76.7 (s), 125.0 (d), 126.4 (d), 127.8 (d), 147.4 (s), 174.2 (s); HRMS (ESI) calcd for $C_{15}H_{25}O_3Si$ ($M + H^+$) 281.1573; found 281.1571.

*4.2.9. Methyl 4-(4-methoxyphenyl)-4-((trimethylsilyl)oxy)pentanoate (**5d**)*: Colorless paste; *Rf* 0.4 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ −0.06 (s, 9H), 1.45 (s, 3H), 1.84-1.92 (m, 3H), 2.08-2.18 (m, 1H), 3.42 (s, 3H), 3.61 (s, 3H), 6.64-6.69 (m, 2H), 7.08-7.13 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 29.2 (t), 29.6 (q), 40.5 (t), 51.2 (q), 55.0 (q), 76.4 (s), 113.1 (d), 126.1 (d), 139.5 (s), 158.1 (s), 174.2 (s); HRMS (ESI) calcd for $C_{16}H_{27}O_4Si$ ($M + H^+$) 311.1679; found 311.1676.

*4.2.10. Methyl 4-(4-fluorophenyl)-4-((trimethylsilyl)oxy)pentanoate (**5e**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.12 (s, 9H), 1.63 (s, 3H), 1.98-2.09 (m, 3H), 2.24-2.35 (m, 1H), 3.60 (s, 3H), 6.95-7.01 (m, 2H), 7.30-7.34 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 29.1 (t), 29.8 (q), 40.5 (t), 51.3 (q), 76.5 (s), 114.5 (d, J_{CCF}=20.7 Hz), 126.7 (d, J_{CCCF}=7.5 Hz), 143.2 (s, J_{CCCCF}=3.6 Hz), 161.4 (s, J_{CF}=244.7 Hz), 174.1 (s); HRMS (ESI) calcd for $C_{15}H_{24}FO_3Si$ ($M + H^+$) 299.1479; found 299.1476.

*4.2.11. Methyl 4-(naphthalen-2-yl)-4-((trimethylsilyl)oxy)pentanoate (**5f**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.15 (s, 9H), 1.74 (s, 3H), 2.01-2.09 (m, 1H), 2.11-2.23 (m, 2H), 2.29-2.39 (m, 1H), 3.55 (s, 3H), 7.42-7.51 (m, 3H), 7.77-7.85 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 2.3 (q), 29.2 (t), 29.6 (q), 40.3 (t), 51.2 (q), 76.9(s), 123.6 (d), 123.8 (d), 125.5 (d), 125.8 (d), 127.3 (d), 127.6 (d), 128.0 (d), 132.2 (s), 133.0 (s), 144.8 (s), 174.1 (s); HRMS (ESI) calcd for $C_{19}H_{28}O_3Si$ ($M + H^+$) 331.1729; found 331.1724.

*4.2.12. Methyl 4-phenyl-4-((trimethylsilyl)oxy)hexanoate (**5g**)*: Colorless paste; *Rf* 0.55 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.19 (s, 9H), 0.65 (t, 3H, *J* = 7.4 Hz), 1.85-1.96 (m, 3H), 2.10-2.32 (m, 3H), 3.57 (s, 3H), 7.16-7.20 (m, 1H), 7.27-7.32 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 8.1 (q), 28.9 (t), 35.6 (t), 37.7 (t), 51.3 (q), 80.4 (s), 125.6 (d), 126.2 (d), 127.8 (d), 144.9 (s), 174.1 (s); HRMS (ESI) calcd for $C_{16}H_{27}O_3Si$ ($M + H^+$) 295.1729; found 295.1726.

*4.2.13. Methyl 4-phenyl-4-((trimethylsilyl)oxy)heptanoate (**5h**)*: Colorless paste; *Rf* 0.55 (hexanes-ethyl acetate, 10:1); IR (ATR) 1738 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.19 (s, 9H), 0.79 (t, 3H, *J* = 7.3 Hz), 0.84-0.95 (m, 1H), 1.16-1.28 (m, 1H), 1.75-1.95 (m, 3H), 2.09-2.32 (m, 3H), 3.58 (s, 3H), 7.16-7.21 (m, 1H), 7.27-7.33 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 14.0 (q), 16.9 (t), 28.8 (t), 37.9 (t), 45.6 (t), 51.3 (q), 80.0 (s), 125.5 (d), 126.1 (d), 127.8 (d), 145.3 (s), 174.1 (s); HRMS (ESI) calcd for $C_{17}H_{29}O_3Si$ ($M + H^+$) 309.1886; found 309.1883.

*4.2.14. Methyl 5-methyl-4-phenyl-4-((trimethylsilyl)oxy)hexanoate (**5i**)*: Colorless paste; *Rf* 0.5

(hexanes-ethyl acetate, 10:1); IR (ATR) 1738 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.22 (s, 9H), 0.75 (d, 3H, *J* = 6.9 Hz), 0.82 (d, 3H, *J* = 6.6 Hz), 1.91-2.04 (m, 2H), 2.13-2.41 (m, 3H), 3.60 (s, 3H), 7.17-7.21 (m, 1H), 7.27-7.31 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 2.5 (q), 17.3 (q), 17.9 (q), 29.4 (t), 34.4 (t), 39.0 (d), 51.3 (q), 83.3 (s), 126.1 (d), 126.3 (d), 127.4 (d), 143.7 (s), 174.2 (s); HRMS (ESI) calcd for $C_{17}H_{29}O_3Si$ ($M + H^+$) 309.1886; found 309.1882.

*4.2.15. Methyl 4-phenyl-4-((trimethylsilyl)oxy)butanoate (**5j**)*: Colorless paste; *Rf* 0.55 (hexanes-ethyl acetate, 10:1); IR (ATR) 1738 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ −0.14 (s, 9H), 1.76-1.88 (m, 2H), 2.13-2.27 (m, 2H), 3.49 (s, 3H), 4.54 (dd, 1H, *J*=5.0, 7.3 Hz), 7.05-7.09 (m, 1H), 7.12-7.15 (m, 4H); ^{13}C NMR ($CDCl_3$) δ −0.1 (q), 30.1 (t), 35.3 (t), 51.4 (q), 73.5 (d), 125.7 (d), 127.1 (d), 128.1 (d), 144.5 (s), 174.0 (s); HRMS (ESI) calcd for $C_{14}H_{23}O_3Si$ ($M + H^+$) 267.1416; found 267.1414.

*4.2.16. Methyl 4-(4-methoxyphenyl)-4-((trimethylsilyl)oxy)butanoate (**5k**)*: Colorless paste; *Rf* 0.45 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.93-1.99 (m, 2H), 2.30-2.41 (m, 2H), 3.65 (s, 3H), 3.80 (s, 3H), 4.65 (t, 1H, *J*=6.3 Hz), 6.83-6.86 (m, 2H), 7.19-7.23 (m, 2H); ^{13}C NMR ($CDCl_3$) δ −0.1 (q), 30.1 (t), 35.3 (t), 51.3 (q), 55.0 (q), 73.2 (d), 113.4 (d), 126.8 (d), 136.6 (s), 158.6 (s), 173.9 (s); HRMS (ESI) calcd for $C_{15}H_{25}O_4Si$ ($M + H^+$) 297.1522; found 297.1520.

*4.2.17. Methyl 4-(4-fluorophenyl)-4-((trimethylsilyl)oxy)butanoate (**5l**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ −0.15 (s, 9H), 1.74-1.83 (m, 2H), 2.12-2.26 (m, 2H), 3.49 (s, 3H), 4.52 (dd, 1H, *J*=5.2, 7.3 Hz), 6.80-6.86 (m, 2H), 7.08-7.12 (m, 2H); ^{13}C NMR ($CDCl_3$) δ −0.1 (q), 30.0 (t), 35.4 (t), 51.5 (q), 72.9 (d), 114.9 (d, J_{CCF}=21.3 Hz), 127.3 (d, J_{CCCF}=8.4 Hz), 140.4 (s, J_{CCCCF}=3.3 Hz), 161.9 (s, J_{CF}=245.0 Hz), 173.9 (s); HRMS (ESI) calcd for $C_{14}H_{22}FO_3Si$ ($M + H^+$) 285.1322; found 285.1320.

*4.2.18. Methyl 4-(benzo[d][1,3]dioxol-5-yl)-4-((trimethylsilyl)oxy)butanoate (**5m**)*: Colorless paste; *Rf* 0.4 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736, 1693 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.03 (s, 9H), 1.91-1.96 (m, 2H), 2.29-2.41 (m, 2H), 3.66, (s, 3H), 4.61 (t, 1H, *J*=6.4 Hz), 5.93-5.95 (m, 2H),

6.71-6.75 (m, 2H), 6.82-6.84 (m, 1H); ^{13}C NMR ($CDCl_3$) δ −0.1 (s), 30.0 (t), 35.4 (t), 51.3 (q), 73.3 (d), 100.8 (t), 106.2 (d), 107.7 (d), 118.9 (d), 138.7 (s), 146.5 (s), 147.4 (s), 173.9 (s); HRMS (ESI) calcd for $C_{15}H_{23}O_5Si$ ($M + H^+$) 311.1315; found 311.1312.

*4.2.19. Methyl 4-(naphthalen-2-yl)-4-((trimethylsilyl)oxy)butanoate (**5n**)*: Colorless paste; *Rf* 0.4 (hexanes-ethyl acetate, 10:1); IR (ATR) 1736, 1697 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.04 (s, 9H), 2.00-2.12 (m, 2H), 2.32-2.48 (m, 2H), 3.65 (s, 3H), 4.86-4.90 (m, 1H), 7.41-7.49 (m, 3H), 7.72-7.74 (m, 1H), 7.79-7.83 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 0.0 (q), 30.1 (t), 35.3 (t), 51.4 (q), 73.7 (d), 124.1 (d), 124.4 (d), 125.6 (d), 126.0 (d), 127.6 (d), 127.9 (d), 128.0 (d), 132.9 (s), 133.2 (s), 142.1 (s), 174.0 (s); HRMS (ESI) calcd for $C_{18}H_{25}O_3Si$ ($M + H^+$) 317.1573; found 317.1570.

*4.2.20. 4,4-Diphenyl-4-((trimethylsilyl)oxy)butanenitrile (**8a**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 2249 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ −0.09 (s, 9H), 2.11-2.16 (m, 2H), 2.67-2.72 (m, 2H), 7.23-7.33 (m, 10H); ^{13}C NMR ($CDCl_3$) δ 1.6 (q), 12.0 (t), 37.3 (t), 79.5 (s), 120.1 (s), 126.7 (d), 127.3 (d), 128.0 (d), 145.2 (s); HRMS (ESI) calcd for $C_{19}H_{24}NOSi$ ($M + H^+$) 310.1627; found 310.1625.

*4.2.21. 4-Hydroxy-4,4-diphenylbutanenitrile (**8h**)*: Colorless paste; *Rf* 0.5 (hexanes-ethyl acetate, 10:1); IR (ATR) 2247 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.16 (s, 9H), 1.67 (s, 3H), 1.93-2.00 (m, 1H), 2.05-2.12 (m, 2H), 2.28-2.35 (m, 1H), 7.22-7.28 (m, 1H), 7.32-7.35 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 2.2 (q), 12.1 (t), 29.6 (q), 41.3 (t), 76.3 (s), 120.2 (s), 124.9 (d), 126.9 (d), 128.2 (d), 146.1 (s); HRMS (ESI) calcd for $C_{14}H_{22}NOSi$ ($M + H^+$) 248.1471; found 248.1469..

*4.2.22. Ethyl 2-(2-Phenyl-2-((trimethylsilyl)oxy)cyclobutyl)acetate (**11a**)*: Diastereomeric mixture (80:20); colorless paste; *Rf* 0.3, 0.25 (hexanes-ethyl acetate, 20:1); ^{1}H NMR ($CDCl_3$) δ −0.10 (s, 7.2H), −0.01 (s, 1.8H), 1.18 (t, 0.6H, *J*=7.0 Hz), 1.24 (t, 2.4H, *J*=7.0 Hz), 1.64-3.16 (m, 7H), 4.02 (q, 0.4H, *J*=7.0 Hz), 4.11 (q, 1.6H, *J*=7.0 Hz), 7.21-7.48 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 1.3 (q), 14.1 (q), 19.9 (t), 32.2 (t), 35.3 (t), 45.1 (d), 59.9 (t), 78.6 (s), 125.6 (d), 126.8 (d), 128.0 (d), 146.4 (s), 173.2 (s); HRMS (ESI) calcd for $C_{17}H_{27}O_3Si$ ($M + H^+$) 307.1729; found 307.1726.

*4.2.23. Ethyl 2-(2-Phenyl-2-((trimethylsilyl)oxy)cyclopentyl)acetate (**11b**)*: Diastereomeric mixture (50:50); colorless paste: *Rf* 0.3 (hexanes-ethyl acetate, 20:1); ^{1}H NMR ($CDCl_3$) δ −0.07 (s, 4.5H), 0.09 (s, 4.5H), 1.19 (t, 1.5H, *J*=7.0 Hz), 1.20 (t, 1.5H, *J*=7.0 Hz), 1.28-2.65 (m, 9H), 4.00 (q, 1H, *J*=7.0 Hz), 4.04 (q, 1H, *J*=7.0 Hz), 7.20-7.42 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 1.6 (q), 1.7 (q), 14.0 (q), 21.0 (t), 21.5 (t), 28.2 (t), 29.6 (t), 33.3 (t), 35.8 (t), 36.7 (t), 39.3 (t), 48.9 (d), 50.7 (d), 59.7 (t), 59.8 (t), 86.3 (s), 86.7 (s), 125.4 (d), 126.3 (d), 126.7 (d), 126.9 (d), 127.6 (d), 127.7 (d), 144.0 (s), 145.5 (s), 172.8 (s), 173.5 (s); HRMS (ESI) calcd for $C_{18}H_{29}O_3Si$ ($M + H^+$) 321.1886; found 321.1883.

*4.2.24. Ethyl 2-(2-phenyl-2-((trimethylsilyl)oxy)cyclohexyl)acetate (**11c**)*: Diastereomeric mixture (50:50); colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 20:1); ^{1}H NMR ($CDCl_3$) δ −0.15 (s, 4.5H), 0.16 (s, 4.5H), 1.15 (t, 1.5H, *J*=7.0 Hz), 1.16 (t, 1.5H, *J*=7.0 Hz), 1.37-2.20 (m, 10.5H), 2.51-2.64 (m, 0.5H), 3.92-4.00 (m, 2H), 7.18-7.43 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 1.8 (q), 2.6 (q), 13.96 (q), 14.00 (q), 19.7 (t), 21.6 (t), 22.1 (t), 25.0 (t), 25.3 (t), 27.7 (t), 30.9 (t), 34.0 (t), 35.5 (t), 38.3 (t), 42.9 (d), 44.8 (d), 59.7 (q), 59.8 (q), 77.1 (s), 80.2 (s), 125.7 (d), 126.1 (d), 126.3 (d), 127.0 (d), 127.6 (d), 127.9 (d), 146.4 (s), 147.0 (s), 172.7 (s), 173.5 (s); HRMS (ESI) calcd for $C_{19}H_{31}O_3Si$ ($M + H^+$) 335.5390; found 335.5386.

4.3. Typical Procedure of Desilylation of 3a-z with TBAF in THF

To a solution of **3a** (86 mg, 0.25 mmol) in THF (5 mL) was added 1 M TBAF in THF (0.25 mL, 0.25 mmol) at 25 ˚C and the mixture was stirred for 15 min. After addition of AcOH (15 mg, 0.25 mmol), the solvent was removed *in vacuo*. The residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **4a** (78 mg) in 95% yield. Compounds **4a**,[3c,8a] **4b**,[12] **4c**,[8a,12] **4h**,[6,8a] **4n**,[6] **4q**,[6] **4t**,[6] **6a**,[3c,8a] **6b**,[13] **6c**,[3c,8a] **6d**,[8a] **6e**,[14] **6g**,[8a] **6h**,[8a] **6j**,[3c,8e] **6k**,[8e] **6l**,[8e] **6m**,[15] **6n**,[8e] **9h**,[3b,8a] **12b**,[16] and **12c**[17] were known.

*4.3.1. 3',4',10,11-Tetrahydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one (**4d**)*: White solid; *Rf* 0.4 (hexanes-ethyl acetate, 5:1); mp 148-149 °C; IR (ATR) 1761 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.57 (t, 2H, *J*=8.2 Hz), 2.92 (t, 2H, *J*=8.2 Hz), 2.99-3.08 (m, 2H), 3.47-3.55 (m, 2H), 7.15-7.24 (m, 6H), 7.59-7.63 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 27.7 (t), 32.4 (t), 38.6 (t), 88.5 (s), 123.6 (d), 126.1 (d),

127.8 (d), 130.8 (d), 136.6 (s), 141.1 (s), 176.1 (s). Anal. Calcd for $C_{18}H_{16}O_2$: C, 81.79; H, 6.10. Found: C, 81.75; H, 6.12.

*4.3.2. 3',4'-Dihydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one (**4e**)*: White solid; *Rf* 0.45 (hexanes-ethyl acetate, 5:1); mp 134-136 °C; IR (ATR) 1765 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.34 (t, 2H, *J*=8.0 Hz), 2.49 (t, 2H, *J*=8.0 Hz), 7.06 (s, 2H), 7.29-7.34 (m, 2H), 7.37-7.43 (m, 4H), 7.75-7.80 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 27.5 (t), 32.2 (t), 87.3 (s), 122.5 (d), 127.1 (d), 128.6 (d), 129.3 (d), 131.3 (d), 131.5 (s), 139.8 (s), 175.9 (s). Anal. Calcd for $C_{18}H_{14}O_2$: C, 82.42; H, 5.38. Found: C, 82.39; H, 5.39.

*4.3.3. 3',4'-Dihydro-5'H-spiro[fluorene-9,2'-furan]-5'-one (**4f**)*: Colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); IR (ATR) 1767 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.69 (t, 2H, *J*=8.5 Hz), 3.07 (t, 2H, *J*=8.5 Hz), 7.31-7.35 (m, 2H), 7.40-7.44 (m, 2H), 7.45-7.48 (m, 2H), 7.63-7.66 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 29.5 (t), 33.0 (t), 90.5 (s), 120.2 (d), 123.3 (d), 128.3 (d), 130.0 (d), 139.5 (s), 145.1 (s), 177.0 (s); HRMS (ESI) calcd for $C_{16}H_{13}O_2$ ($M + H^+$) 237.0916; found 237.0915.

*4.3.4. 3,4-Dihydro-5H-spiro[furan-2,9'-xanthen]-5-one (**4g**)*: White solid; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); mp 110-112 °C; IR (ATR) 1757 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.58 (t, 2H, *J*=8.3 Hz), 2.95 (t, 2H, *J*=8.3 Hz), 7.18-7.26 (m, 4H), 7.36-7.43 (m, 2H), 7.43-7.49 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.8 (t), 40.8 (t), 79.8 (s), 116.8 (d), 123.8 (d), 125.0 (d), 129.6 (d), 149.6 (s), 176.4 (s). Anal. Calcd for $C_{16}H_{12}O_3$: C, 76.18; H, 4.79. Found: C, 76.13; H, 4.82.

*4.3.5. 5,5-Bis(4-methoxyphenyl)-4-methyldihydrofuran-2(3H)-one (**4i**)*: White solid; *Rf* 0.2 (hexanes-ethyl acetate, 5:1); mp 109-111 ºC; IR (ATR) 1771, 1753 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.90 (d, 3H, *J*=7.0 Hz), 2.31 (dd, 1H, *J*=5.6, 17.2 Hz), 2.71 (dd, 1H, *J*=7.5, 17.2 Hz), 3.31-3.39 (m, 1H), 3.78 (s, 3H), 3.80 (s, 3H), 6.80-6.85 (m, 2H), 6.86-6.90 (m, 2H), 7.10-7.14 (m, 2H), 7.37-7.42 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 16.9 (q), 37.3 (t), 37.9 (d), 54.9 (q), 55.0 (q), 91.9 (s), 113.2 (d), 113.6 (d), 126.8 (d), 127.3 (d), 132.8 (s), 134.9 (s), 158.5 (s), 159.0 (s), 175.7 (s). Anal. Calcd for $C_{19}H_{20}O_4$: C, 73.06; H, 6.45. Found: C, 73.01; H, 6.47.

*4.3.6 5,5-Bis(4-fluorophenyl)-4-methyldihydrofuran-2(3H)-one (**4j**)*: Colorless paste; *Rf* 0.25 (hexanes-ethyl acetate, 5:1); IR (ATR) 1782 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.90 (d, 3H, *J*=6.9 Hz), 2.33 (dd, 1H, *J*=4.6, 17.2 Hz), 2.72 (dd, 1H, *J*=7.5, 17.2 Hz), 3.33-3.41 (m, 1H), 6.98-7.09 (m, 4H), 7.17-7.22 (m, 2H), 7.44-7.49 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 17.0 (q), 37.3 (t), 38.0 (d), 91.3 (s), 115.1 (d, J_{CCF}=21.3 Hz), 115.5 (d, J_{CCF}=21.6 Hz), 127.3 (d, J_{CCCF}=7.8 Hz), 128.0 (d, J_{CCCF}=8.4 Hz), 136.1 (s, J_{CCCCF}=3.6 Hz), 138.4 (s, J_{CCCCF}=3.6 Hz), 161.9 (s, J_{CF}=247.1 Hz), 162.3 (s, J_{CF}=248.0 Hz), 175.2 (s); HRMS (ESI) calcd for $C_{17}H_{15}F_2O_2$ ($M + H^+$) 289.1040; found 289.1037.

*4.3.7. 3'-Methyl-3',4',10,11-tetrahydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one (**4k**)*: White solid; *Rf* 0.35 (hexanes-ethyl acetate, 5:1); mp 163-165 ºC; IR (ATR) 1761 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.87 (d, 3H, *J*=7.3 Hz), 2.22 (d, 1H, *J*=17.2 Hz), 2.74 (dd, 1H, *J*=7.6, 17.2 Hz), 2.90-2.98 (m, 1H), 3.06-3.14 (m, 1H), 3.26-3.34 (m, 1H), 3.41-3.54 (m, 2H), 7.09-7.23 (m, 6H), 7.45-7.49 (m, 1H), 7.71-7.75 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 17.6 (q), 32.2 (t), 32.4 (t), 36.4 (t), 40.6 (d), 91.7 (s), 123.6 (d), 125.2 (d), 126.0 (d), 126.3 (d), 127.9 (d), 130.1 (d), 131.6 (d), 136.2 (s), 136.5 (s), 138.5 (s), 140.4 (s), 176.2 (s). Anal. Calcd for $C_{19}H_{18}O_2$: C, 81.99; H, 6.52. Found: C, 81.92; H, 6.50.

*4.3.8. 3'-Methyl-3',4'-dihydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one (**4l**)*: White solid; *Rf* 0.5 (hexanes-ethyl acetate, 5:1); mp 137-138 °C; IR (ATR) 1780, 1763, 1684 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.54 (d, 3H, *J*=7.4 Hz), 2.06 (d, 2H, *J*=17.2 Hz), 2.43 (dd, 1H, *J*=8.0, 17.2 Hz), 2.99-3.07 (m, 1H), 7.04 (d, 1H, *J*=12.0 Hz), 7.07 (d, 1H, *J*=12.0 Hz), 7.28-7.44 (m, 6H), 7.65-7.70 (m, 1H), 7.83-7.88 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 17.6 (q), 34.8 (d), 36.1 (t), 90.5 (s), 122.9 (d), 123.9 (d), 127.1 (d), 127.2 (d), 128.5 (d), 128.7 (d), 128.8 (d), 129.3 (d), 131.2 (d), 131.3 (d), 131.8 (s), 131.9 (s), 136.6 (s), 139.7 (s), 176.0 (s). Anal. Calcd for $C_{19}H_{18}O_2$: C, 82.58; H, 5.84. Found: C, 82.54; H, 5.87

*4.3.9. 3-Methyl-3,4-dihydro-5H-spiro[furan-2,9'-xanthen]-5-one (**4m**)*: Colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); IR (ATR) 1775, 1751, 1655 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.63 (d, 3H, *J*=6.9 Hz), 2.54 (dd, 1H, *J*=11.6, 17.0 Hz), 2.62-2.71 (m, 1H), 2.80 (dd, 1H, *J*=8.0, 17.0 Hz),

7.16-7.29 (m, 5H), 7.34-7.43 (m, 2H), 7.55-7.59 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 13.8 (q), 35.8 (t), 47.1 (d), 83.2 (s), 116.4 (d), 116.9 (d), 120.0 (s), 123.5 (d), 124.0 (s), 124.1 (d), 125.1 (d), 125.2 (d), 129.4 (d), 129.7 (d), 150.2 (s), 150.8 (s), 176.4 (s); HRMS (ESI) calcd for $C_{17}H_{15}O_3$ ($M + H^+$) 267.1021; found 267.1019.

*4.3.10. 4'-Methyl-3',4',10,11-tetrahydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one (**4o**)*: White solid; *Rf* 0.5 (hexanes-ethyl acetate, 5:1); mp 155 °C; IR (ATR) 1769 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.24 (d, 3H, *J*=7.5 Hz), 2.39 (t, 1H, *J*=12.0 Hz), 2.63-2.73 (m, 1H), 2.92-3.01 (m, 1H), 3.05-3.14 (m, 1H), 3.35 (dd, 1H, *J*=9.2, 12.0 Hz), 3.45-3.59 (m, 2H), 7.12-7.24 (m, 1H), 7.49-7.53 (m, 1H), 7.69-7.73 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 14.8 (q), 32.4 (t), 32.7 (t), 34.2 (d), 47.1 (t), 86.4 (s), 123.7 (d), 124.0 (d), 126.2 (d), 126.6 (d), 127.9 (d), 128.1 (d), 130.5 (d), 131.4 (d), 136.6 (s), 136.8 (s), 140.3 (s), 142.6 (s), 178.9 (s). Anal. Calcd for $C_{19}H_{18}O_2$: C, 81.99; H, 6.52. Found: C, 81.96; H, 6.54.

*4.3.11. 4-Methyl-3,4-dihydro-5H-spiro[furan-2,9'-xanthen]-5-one (**4p**)*: Colorless paste; *Rf* 0.4 (hexanes-ethyl acetate, 5:1); IR (ATR) 1765, 1722 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.40 (d, 3H, *J*=7.3 Hz), 2.18 (dd, 1H, *J*=9.5, 13.3 Hz), 2.74 (dd, 1H, *J*=9.5, 13.3 Hz), 3.11-3.20 (m, 1H), 7.16-7.24 (m, 4H), 7.34-7.40 (m, 3H), 7.49-7.51 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 15.7 (q), 34.7 (d), 49.4 (t), 77.6 (s), 116.5 (d), 117.0 (d), 123.7 (d), 123.8 (s), 124.0 (d), 124.5 (d), 124.7 (s), 125.2 (d), 129.4 (d), 129.5 (d), 149.7 (s), 150.0 (s), 179.2 (s); HRMS (ESI) calcd for $C_{17}H_{15}O_3$ ($M + H^+$) 267.1021; found 267.1019.

*4.3.12. 5,5-Bis(4-methoxyphenyl)-4-phenyldihydrofuran-2(3H)-one (**4r**)*: Colorless paste; *Rf* 0.2 (hexanes-ethyl acetate, 5:1); IR (ATR) 1771, 1730 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.81 (dd, 1H, *J*=5.7, 17.2 Hz), 2.96 (dd, 1H, *J*=8.0, 17.2 Hz), 3.68 (s, 3H), 3.80 (s, 3H), 4.43 (dd, 1H, *J*=5.7, 8.0 Hz), 6.57-6.62 (m, 2H), 6.85-6.93 (m, 6H), 7.11-7.15 (m, 3H), 7.49-7.53 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 37.1 (t), 51.0 (d), 55.1 (q), 55.3 (q), 92.8 (s), 112.9 (d), 113.8 (d), 127.3 (d), 127.6 (d), 127.7 (d), 128.3 (d), 128.6 (d), 132.1 (s), 135.2 (s), 138.1 (s), 158.5 (s), 159.2 (s), 175.9 (s); HRMS (ESI)

calcd for $C_{24}H_{23}O_4$ ($M + H^+$) 375.1596; found 375.1594.

4.3.13. 5,5-Bis(4-fluorophenyl)-4-phenyldihydrofuran-2(3H)-one ***(4s)***: White solid; *Rf* 0.4 (hexanes-ethyl acetate, 5:1); mp 124-125 ºC; IR (ATR) 1769, 1738 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.82 (dd, 1H, *J*=4.8, 17.2 Hz), 2.99 (dd, 1H, *J*=8.0, 17.2 Hz), 4.43 (dd, 1H, *J*=4.8, 8.0 Hz), 6.73-6.80 (m, 2H), 6.88-6.99 (m, 4H), 7.06-7.17 (m, 5H), 7.56-7.62 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 37.0 (t), 50.8 (d), 92.0 (s), 114.6 (d, J_{CCF}=21.6 Hz), 115.6 (d, J_{CCF}=21.6 Hz), 127.5 (d), 127.97 (d, J_{CCCF}=8.4 Hz), 127.98 (d, J_{CCCF}=8.4 Hz), 128.36 (d), 128.43 (d), 135.6 (d, J_{CCCCF}=2.4 Hz), 137.9 (s), 138.6 (s, J_{CCCCF}=3.6 Hz), 161.6 (s, J_{CF}=247.1 Hz), 162.3 (s, J_{CF}=248.3 Hz), 175.2 (s). Anal. Calcd for $C_{22}H_{16}F_2O_2$: C, 75.42; H, 4.60. Found: C, 75.36; H, 4.65.

4.3.14. 3'-Phenyl-3',4'-dihydro-5'H-spiro[dibenzo[a,d][7]annulene-5,2'-furan]-5'-one ***(4u)***: Colorless paste; *Rf* 0.45 (hexanes-ethyl acetate, 5:1); IR (ATR) 1775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.46 (d, 1H, *J*=17.8 Hz), 2.79 (dd, 1H, *J*=8.6, 17.8 Hz), 4.07 (d, 1H, *J*=8.6 Hz), 6.90 (d, 1H, J=12.0 Hz), 6.92-7.05 (m, 7H), 7.14 (d, 1H, *J*=12.0 Hz), 7.19-7.24 (m, 1H), 7.33-7.37 (m, 1H), 7.42-7.47 (m, 2H), 7.74-7.79 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 36.4 (t), 46.9 (d), 91.5 (s), 122.9 (d), 123.9 (d), 126.6 (d), 126.8 (d), 127.2 (d), 127.4 (d), 127.8 (d), 128.3 (d), 128.5 (d), 128.9 (d), 129.5 (d), 130.3 (d), 131.6 (s), 131.8 (s), 133.0 (s), 136.5 (s), 140.0 (s), 140.4 (s), 176.3 (s); HRMS (ESI) calcd for $C_{24}H_{19}O_2$ ($M + H^+$) 339.1385; found 339.1383.

4.3.15. 3-Phenyl-3,4-dihydro-5H-spiro[furan-2,9'-xanthen]-5-one ***(4v)***: White solid; *Rf* 0.45 (hexanes-ethyl acetate, 5:1); mp 166-167 ºC; IR (ATR) 1798, 1771, 1734 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.99 (dd, 1H, *J*=8.2, 17.7 Hz), 3.24 (dd, 1H, *J*=12.3, 17.7 Hz), 3.79 (dd, 1H, *J*=8.2, 12.3 Hz), 6.40-6.46 (m, 2H), 6.81-6.86 (m, 1H), 6.95-7.02 (m, 2H), 7.05-7.16 (m, 3H), 7.20-7.41 (m, 4H), 7.67-7.72 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 33.4 (t), 58.0 (d), 83.6 (s), 116.2 (d), 116.5 (d), 119.9 (s), 123.1 (d), 123.5 (s), 124.1 (d), 124.5 (d), 124.7 (d), 127.5 (d), 127.8 (d), 127.9 (d), 129.5 (d), 129.6 (d), 133.5 (s), 150.3 (s), 150.7 (s), 175.7 (s). Anal. Calcd for $C_{22}H_{16}O_3$: C, 80.47; H, 4.91. Found: C, 80.46; H, 4.94.

*4.3.16. 4-(4-Methoxyphenyl)-5,5-diphenyldihydrofuran-2(3H)-one (**4w**)*: White solid; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); mp 131-132 ºC; IR (ATR) 1786, 1769 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.76 (dd, 1H, *J*=5.4, 17.3 Hz), 2.96 (dd, 1H, *J*=8.0, 17.3 Hz), 3.72 (s, 3H), 4.44 (dd, 1H, *J*=5.4, 8.0 Hz), 6.64-6.68 (m, 2H), 6.81-6.85 (m, 2H), 7.02-7.13 (m, 5H), 7.30-7.34 (m, 1H), 7.36-7.41 (m, 2H), 7.61-7.65 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 37.4 (t), 50.2 (d), 55.0 (q), 92.8 (s), 113.6 (d), 126.0 (d), 126.2 (d), 127.1 (d), 127.6 (d), 128.0 (d), 128.5 (d), 129.5 (d), 130.1 (s), 139.8 (s), 143.1 (s), 158.5 (s), 175.8 (s). Anal. Calcd for $C_{23}H_{20}O_3$: C, 80.21; H, 5.85. Found: C, 80.26; H, 5.82.

*4.3.17. 4-(4-Fluorophenyl)-5,5-diphenyldihydrofuran-2(3H)-one (**4x**)*: White solid; *Rf* 0.35 (hexanes-ethyl acetate, 5:1); mp 154-156 ºC; IR (ATR) 1771 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.75 (dd, 1H, *J*=4.5, 17.5 Hz), 2.99 (dd, 1H, *J*=8.0, 17.5 Hz), 4.48 (dd, 1H, *J*=4.5, 8.0 Hz), 6.77-6.84 (m, 2H), 6.87-6.93 (m, 2H), 7.01-7.12 (m, 5H), 7.30-7.35 (m, 1H), 7.37-7.42 (m, 2H), 7.60-7.65 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 37.5 (t), 50.1 (d), 92.8 (s), 115.2 (d, J_{CCF}=21.6 Hz), 126.0 (d), 126.1 (d), 127.3 (d), 127.8 (d), 128.2 (d), 128.7 (d), 130.0 (d, J_{CCCF}=8.4 Hz), 134.3 (s, J_{CCCCF}=3.6 Hz), 139.8 (s), 142.8 (s), 161.8 (s, J_{CF}=247.1 Hz), 175.5 (s). Anal. Calcd for $C_{22}H_{17}FO_2$: C, 79.50; H, 5.16. Found: C, 79.55; H, 5.17.

*4.3.18. 4-(Benzo[d][1,3]dioxol-5-yl)-5,5-diphenyldihydrofuran-2(3H)-one (**4y**)*: White solid; *Rf* 0.25 (hexanes-ethyl acetate, 5:1); mp 198-200 ºC; IR (ATR) 1763 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.72 (dd, 1H, *J*=5.0, 17.5 Hz), 2.95 (dd, 1H, *J*=8.0, 17.5 Hz), 4.41 (dd, 1H, *J*=5.0, 8.0 Hz), 5.85-5.87 (m, 2H), 6.34 (d, 1H, *J*=1.7 Hz), 6.48 (dd, 1H, *J*=1.7, 8.0 Hz), 6.59 (d, 1H, *J*=8.0 Hz), 7.07-7.15 (m, 5H), 7.29-7.34 (m, 1H), 7.36-7.41 (m, 2H), 7.60-7.63 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 37.5 (t), 50.7 (d), 92.8 (d), 101.0 (t), 107.9 (d), 108.6 (d), 122.0 (d), 125.9 (d), 126.2 (d), 127.2 (d), 127.7 (d), 128.1 (d), 128.6 (d), 132.1 (s), 139.8 (s), 143.1 (s), 146.6 (s), 147.5 (s), 175.6 (s). Anal. Calcd for $C_{23}H_{18}O_4$: C, 77.08; H, 5.06. Found: C, 77.02; H, 5.06.

*4.3.19. 4-(Naphthalen-2-yl)-5,5-diphenyldihydrofuran-2(3H)-one (**4z**)*: White solid; *Rf* 0.35 (hexanes-ethyl acetate, 5:1); mp 213-215 ºC; IR (ATR) 1767 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.88 (dd, 1H,

J=5.2, 17.6 Hz), 3.06 (dd, 1H, *J*=8.2, 17.6 Hz), 4.66 (dd, 1H, *J*=5.2, 8.2 Hz), 6.92-6.96 (m, 1H), 7.00-7.05 (m, 3H), 7.07-7.12 (m, 2H), 7.31-7.36 (m, 1H), 7.38-7.46 (m, 4H), 7.49 (brs, 1H), 7.56 (d, 1H, *J*=8.6 Hz), 7.67-7.73 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 37.5 (t), 51.2 (d), 92.8 (s), 125.97 (d), 126.01 (d), 126.1 (d), 126.16 (d), 126.21 (d), 127.2 (d), 127.4 (d), 127.6 (d), 127.9 (d), 128.1 (d), 128.6 (d), 132.3 (s), 132.9 (s), 135.9 (s), 139.8 (s), 143.2 (s), 175.5 (s). Anal. Calcd for $C_{26}H_{20}O_2$: C, 85.69; H, 5.53. Found: C, 85.73; H, 5.57.

*4.3.20. 5-Methyl-5-(naphthalen-2-yl)dihydrofuran-2(3H)-one (**6f**)*: Colorless paste; *Rf* 0.25 (hexanes-ethyl acetate, 5:1); IR (ATR) 1761 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.81 (s, 3H), 2.44-2.71 (m, 4H), 7.41-7.53 (m, 3H), 7.81-7.88 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 28.6 (t), 28.9 (q), 35.6 (t), 86.7 (s), 122.2 (d), 122.3 (d), 126.0 (d), 126.3 (d), 127.3 (d), 127.9 (d), 128.3 (d), 132.3 (s), 132.6 (s), 141.2 (s), 176.3 (S); HRMS (ESI) calcd for $C_{15}H_{15}O_2$ (M + H$^+$) 227.1072; found 227.1069.

*4.3.21. 5-Isopropyl-5-phenyldihydrofuran-2(3H)-one (**6i**)*: Colorless paste; *Rf* 0.2 (hexanes-ethyl acetate, 10:1); IR (ATR) 1765 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.86 (d, 3H *J*=6.9 Hz), 0.92 (d, 3H *J*=6.9 Hz), 2.11-2.19 (m, 1H), 2.36-2.44 (m, 1H), 2.48-2.58 (m, 3H), 7.27-7.38 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 16.7 (q), 17.1 (q), 28.7 (t), 31.8 (t), 37.9 (d), 91.8 (s), 125.4 (d), 127.2 (d), 127.8 (d), 141.3 (s), 176.4 (S); HRMS (ESI) calcd for $C_{13}H_{17}O_2$ (M + H$^+$) 205.2729; found 205.2727.

*4.3.22. 4-Hydroxy-4,4-diphenylbutanenitrile (**9a**)*: Colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); IR (ATR) 3447, 2249 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.12 (s, 1H), 2.29-2.34 (m, 2H), 2.65-2.71 (m, 2H), 7.26-7.31 (m, 2H), 7.32-7.39 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 12.1 (t), 37.6 (t), 77.4 (s), 120.4 (s), 125.9 (d), 127.5 (d), 128.5 (d), 145.2 (s); HRMS (ESI) calcd for $C_{16}H_{16}NO$ (M + H$^+$) 238.1232; found 238.1230.

4.3.23. (1R,5R*)-1-Phenyl-2-oxabicyclo[3.2.0]heptan-3-one (**12a**)*: Colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); IR (ATR) 1771 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.86-1.96 (m, 1H), 2.35-2.44 (m, 1H), 2.56-2.65 (m, 2H), 2.67-2.75 (m, 1H), 2.81 (dd, 1H, *J*=8.6, 18.3 Hz), 3.25-3.31 (m, 1H), 7.30-7.42 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 21.8 (t), 33.4 (t), 36.2 (t), 40.2 (d), 90.4 (s), 124.5 (d),

128.0 (d), 128.5 (d), 140.6 (s), 177.3 (s); HRMS (ESI) calcd for $C_{12}H_{13}O_2$ (M + H^+) 189.0916; found 189.0915.

4.3.24. Ethyl 2-((1R,2S*)-2-hydroxy-2-phenylcyclobutyl)acetate (**13a**)*: Colorless paste; *Rf* 0.2 (hexanes-ethyl acetate, 5:1); IR (ATR) 3426, 1730, 1713 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16 (t, 3H, *J*=7.2 Hz), 1.44-1.53 (m, 1H), 1.88-2.01 (m, 2H), 2.08-2.18 (m, 1H), 2.31-2.41 (m, 1H), 2.63-2.71 (m, 1H), 2.94-3.06 (m, 2H), 3.97-4.07 (m, 2H), 7.25-7.47 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 14.1 (q), 19.2 (t), 34.4 (t), 36.0 (t), 45.0 (d), 60.3 (t), 78.1 (s), 125.6 (d), 127.2 (d), 128.2 (d), 142.3 (s), 173.1 (s); HRMS (ESI) calcd for $C_{14}H_{19}O_3$ (M + H^+) 235.1334 found 235.1332.

4.3.25. Ethyl 2-((1R,2S*)-2-hydroxy-2-phenylcyclopentyl)acetate (**13b**)*: Colorless paste; *Rf* 0.25 (hexanes-ethyl acetate, 5:1); IR (ATR) 3460, 1730, 1713 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16 (t, 3H, *J*=7.3 Hz), 1.44-1.54 (m, 1H), 1.82-2.15 (m, 6H), 2.28-2.37 (m, 1H), 2.56-2.66 (m, 1H), 3.12 (brs, 1H), 4.00 (q, 2H, *J*=7.3 Hz), 7.22-7.27 (m, 1H), 7.30-7.40 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 14.0 (q), 21.9 (t), 30.9 (t), 36.6 (t), 39.8 (t), 48.2 (d), 60.4 (t), 84.1 (s), 126.0 (d), 126.8 (d), 127.9 (d), 144.8 (s), 173.7 (s); HRMS (ESI) calcd for $C_{15}H_{21}O_3$ (M + H^+) 249.1491; found 249.1489.

4.3.26. Ethyl 2-((1R,2S*)-2-hydroxy-2-phenylcyclohexyl)acetate (**13c**)*: Colorless paste; *Rf* 0.3 (hexanes-ethyl acetate, 5:1); IR (ATR) 3495, 1730, 1717 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.15 (t, 3H, *J*=7.3 Hz), 1.42-1.59 (m, 3H), 1.66-1.91 (m, 5H), 2.04-2.19 (m, 2H), 2.23 (dd, 1H, *J*=10.5, 15.5 Hz), 2.46-2.53 (m, 1H), 3.92-3.99 (m, 2H), 7.23-7.28 (m, 1H), 7.30-7.37 (m, 2H), 7.45-7.51 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.1 (q), 20.1 (t), 21.4 (t), 25.7 (t), 32.5 (t), 34.8 (t), 41.7 (d), 60.2 (t), 74.5 (s), 125.7 (d), 127.2 (d), 128.2 (d), 146.8 (s), 172.9 (s); HRMS (ESI) calcd for $C_{16}H_{23}O_3$ (M + H^+) 263.1647; found 263.1646.

*4.3.27. Ethyl (E)-9-hydroxy-9-phenylnon-2-enoate (**iii**)*: Colorless paste; *Rf* 0.25 (hexanes-ethyl acetate, 5:1); IR (ATR) 1717, 1699, 1651 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.24-1.49 (m, 6H), 1.28 (t, 3H, *J*=7.2 Hz), 1.66-1.74 (m, 1H), 1.76-1.85 (m, 1H), 2.14-2.20 (m, 2H), 4.18 (q, 2H, J=7.2Hz), 4.66 (dd, 1H, *J*=5.8, 7.5 Hz), 5.77-5.81 (m, 1H), 6.94 (dt, 1H, *J*=6.9, 15.5 Hz), 7.25-7.30 (m, 1H),

7.32-7.38 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 14.2 (q), 25.5 (t), 27.8 (t), 28.9 (t), 32.0 (t), 38.8 (t), 60.1 (t), 74.4 (d), 121.2 (d), 125.8 (d), 127.4 (d), 128.4 (d), 144.8 (s), 149.3 (d), 166.8 (s); HRMS (ESI) calcd for $C_{17}H_{25}O_3$ ($M + H^+$) 277.1804; found 277.1803.

*4.3.28. Ethyl (E)-9-oxo-9-(4-(trimethylsilyl)phenyl)non-2-enoate (**iv**):* Colorless paste; *Rf* 0.6 (hexanes-ethyl acetate, 5:1); IR (ATR) 1717, 1684, 1653 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ −0.29 (s, 9H), 1.29 (t, 3H, *J*=7.2 Hz), 1.38-1.46 (m, 2H), 1.48-1.56 (m, 2H), 1.71-1.79 (m, 2H), 2.19-2.25 (m, 2H), 2.96 (t, 2H, *J*=7.3 Hz), 4.18 (q, 2H, *J*=7.2Hz), 5.81 (d, 1H, *J*=15.6 Hz), 6.92-6.99 (m, 1H), 7.60-7.64 (m, 2H), 7.89-7.92 (m, 2H); ^{13}C NMR ($CDCl_3$) δ −1.4 (q), 14.2 (q), 24.0 (t), 27.8 (t), 28.8 (t), 31.9 (t), 38.3 (t), 60.1 (t), 121.4 (d), 126.9 (d), 133.5 (d), 137.0 (s), 146.9 (s), 149.0 (d), 166.6 (s), 200.4 (s); HRMS (ESI) calcd for $C_{20}H_{30}O_3Si$ ($M + H^+$) 347.2042; found 347.2038.

4.4. Typical procedure of electroreductive coupling of 14 with 2a

A 0.3 M solution of Et_4NOTs in DMF (15 mL) was placed in the cathodic chamber of a divided cell (40 mL beaker, 3 cm diameter, 6 cm height) equipped with a platinum cathode (5 X 5 cm^2), a platinum anode (2 X 1 cm^2), and a ceramic cylindrical diaphragm (1.5 cm diameter). A 0.3 M solution of Et_4NOTs in DMF (4 mL) was placed in the anodic chamber (inside the diaphragm). Aldimine **14a** (211 mg, 1.0 mmol), methyl acrylate (**2a**) (0.45 mL, 5.0 mmol), TMSCl (0.64 mL, 5.0 mmol), and TEA (0.70 mL, 5.0 mmol) were added to the cathodic chamber. After 300 C (3 *F*/mol for **14a**) of electricity was passed at a constant current of 200 mA at 25 ºC under nitrogen atmosphere, the catholyte was poured into water (50 mL) and the aqueous solution was extracted with ether (20 mL X 3). After removal of the solvent in vacuo, the residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **15a** (188 mg) in 63% yield. Compounds **15a**,[7] **19a**,[7] and **19c**[7] were known.

*4.4.1. Methyl 4-(4-chlorophenyl)-4-((4-methoxyphenyl)amino)butanoate (**15b**)*: Colorless paste; *Rf* 0.3 (hexane-ethyl acetate, 5:1); IR (neat) 3383, 1732, 1688 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.02-2.15 (m, 2H), 2.37-2.44 (m, 2H), 3.67 (s, 3H), 3.69 (s, 3H), 4.28 (t, 1H, *J*=6.9 Hz), 6.42-6.46 (m, 2H), 6.66-6.70 (m, 2H), 7.25-7.30 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 30.6 (t), 33.0 (t), 51.4 (q), 55.4 (q), 57.6

(d), 114.4 (d), 114.5 (d), 127.6 (d), 128.5 (d), 132.4 (s), 140.9 (s), 141.9 (s), 151.8 (s), 173.6 (s); HRMS (ESI) calcd for $C_{18}H_{21}ClNO_3$ (M + H^+) 334.1210; found 334.1207.

*4.4.2. Methyl 4-(4-methoxyphenyl)-4-((4-methoxyphenyl)amino)butanoate (**15c**)*: Colorless paste; *Rf* 0.25 (hexane-ethyl acetate, 5:1); IR (neat) 3385, 1734, 1684 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.00-2.18 (m, 2H), 2.38 (t, 2H, *J*=7.3H_Z), 3.66 (s, 3H), 3.69 (s, 3H), 3.78 (s, 3H), 4.25 (t, 1H, *J*=6.9 Hz), 6.45-6.49 (m, 2H), 6.66-6.70 (m, 2H), 6.83-6.86 (m, 2H), 7.21-7.25 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 30.8 (t), 33.1 (t), 51.4 (q), 55.0 (q), 55.5 (q), 57.6 (d), 114.4 (d), 114.5 (d), 127.3 (d), 130.1 (d), 135.1 (s), 141.3 (s), 151.7 (s), 158.5 (s), 173.8 (s); HRMS (ESI) calcd for $C_{19}H_{24}NO_4$ (M + H^+) 330.1705; found 330.1703.

*4.4.3 Methyl 4-(2-methoxyphenyl)-4-((4-methoxyphenyl)amino)butanoate (**15d**)*: Colorless paste; *Rf* 0.3 (hexane-ethyl acetate, 5:1); IR (neat) 3385, 1734, 1686 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.06-2.21 (m, 2H), 2.33-2.48 (m, 2H), 3.64 (s, 3H), 3.68 (s, 3H), 3.87 (s, 3H), 4.65 (t, 1H, *J*=6.9 Hz), 6.48-6.53 (m, 2H), 6.65-6.69 (m, 2H), 6.85-6.89 (m, 2H), 7.16-7.21 (m, 1H), 7.22-7.25 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 31.1 (t), 31.2 (t), 51.3 (q), 53.1 (d), 55.1 (q), 55.4 (q), 110.3 (d), 114.4 (d), 114.5 (d), 120.6 (d), 127.1 (d), 127.8 (d), 130.6 (s), 141.5 (s), 151.6 (s), 156.8 (s), 174.0 (s); HRMS (ESI) calcd for $C_{19}H_{24}NO_4$ (M + H^+) 330.1705; found 330.1703.

*4.4.4. Methyl 4-(4-fluorophenyl)-4-((4-methoxyphenyl)amino)butanoate (**15e**):* Colorless paste; *Rf* 0.3 (hexane-ethyl acetate, 5:1); IR (neat) 3371, 1736, 1686 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.01-2.16 (m, 2H), 2.37-2.43 (m, 2H), 3.67 (s, 3H), 3.69 (s, 3H), 4.29 (t, 1H, *J*=6.9 Hz), 6.42-6.47 (m, 2H), 6.66-6.70 (m, 2H), 6.97-7.02 (m, 2H), 7.27-7.31 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 30.7 (t), 33.2 (t), 51.5 (q), 55.5 (q), 57.6 (d), 114.5 (d), 114.6 (d), 115.3 (d, J_{CCF}=21.1 Hz), 127.8 (d, J_{CCCF}=8.6 Hz), 139.0 (s, J_{CCCCF}=2.9 Hz), 141.1 (s), 151.9 (s), 161.7 (s, J_{CF}=243.8 Hz), 173.7 (s); HRMS (ESI) calcd for $C_{18}H_{21}FNO_3$ (M + H^+) 318.1505; found 318.1502.

*4.4.5. Methyl 4-(4-cyanophenyl)-4-((4-methoxyphenyl)amino)butanoate (**15f**)*: Colorless paste; *Rf* 0.4 (hexane-ethyl acetate, 2:1); IR (neat) 3374, 2226, 1728 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.07-2.12 (m, 2H), 2.39-2.51 (m, 2H), 3.68 (s, 3H), 3.69 (s, 3H), 4.37 (t, 1H, *J*=6.7 Hz), 6.38-6.42 (m, 2H),

6.66-6.70 (m, 2H), 7.45-7.48 (m, 2H), 7.60-7.63 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 30.6 (t), 32.8 (t), 51.6 (q), 55.5 (q), 58.0 (d), 110.7 (s), 114.3 (d), 114.6 (s), 118.7 (s), 127.1 (d), 132.4 (d), 140.9 (s), 140.5 (s), 149.3 (s), 152.0 (d), 173.5 (s); HRMS (ESI) calcd for $C_{19}H_{21}N_2O_3$ ($M + H^+$) 325.1552; found 325.1550.

*4.4.6. Methyl 4-((4-methoxyphenyl)amino)-4-(naphthalen-1-yl)butanoate (**15g**)*: White solid; *Rf* 0.35 (hexane-ethyl acetate, 5:1); mp 96-98 °C; IR (neat) 3408, 1734, 1686 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.10-2.20 (m, 1H), 2.32-2.41 (m, 1H), 2.45-2.66 (m, 2H), 3.66 (s, 3H), 3.67 (s, 3H), 5.16-5.22 (m, 1H), 6.41-6.50 (m, 2H), 6.61-6.67 (m, 2H), 7.40 (t, 1H, *J*=7.8 Hz), 7.49-7.53 (m, 1H), 7.55-7.61 (m, 3H), 7.75 (d, 1H, *J*=8.3Hz), 7.90 (d, 1H, *J*=8.3Hz), 8.22 (d, 1H, *J*=8.3Hz); ^{13}C NMR ($CDCl_3$) δ 30.8 (t), 32.0 (t), 51.4 (q), 53.6 (d), 55.4 (q), 114.1 (d), 114.6 (d), 122.3 (d), 122.7 (d), 125.3 (d), 125.5 (d), 126.0 (d), 127.4 (d), 129.0 (d), 130.8 (s), 133.9 (s), 138.4 (s), 141.1 (s), 151.6 (s), 173.9 (s). Anal. Calcd for $C_{22}H_{23}NO_3$: C, 75.62; H, 6.63; N, 4.01. Found: C, 75.58; H, 6.62; N, 3.91.

*4.4.7. Methyl 4-((4-methoxyphenyl)amino)-4-(naphthalen-2-yl)butanoate (**15h**)*: White solid; *Rf* 0.25 (hexane-ethyl acetate, 2:1); mp 121-123 °C; IR (ATR) 3352, 1724 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.13-2.16 (m, 2H), 2.44 (t, 2H, *J*=7.3 Hz), 3.65 (s, 3H), 3.66 (s, 3.H), 4.08 (brs, 1H), 4.46 (t, 1H, *J*=6.8 Hz), 6.49-6.53 (m, 2H), 6.64-6.68 (m, 2H), 7.41-7.48 (m, 3H), 7.76-7.83 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 30.8 (t), 33.0 (t), 51.4 (q), 55.4 (q), 58.4 (d), 114.5 (d), 114.6 (d), 124.4 (d), 125.1 (d), 125.4 (d), 125.9 (d), 127.5 (d), 127.6 (d), 128.4 (d), 132.6 (s), 133.2 (s), 140.7 (s), 141.3 (s), 151.8 (s), 173.8 (s). Anal. Calcd for $C_{22}H_{23}NO_3$: C, 75.62; H, 6.63; N, 4.01. Found: C, 75.56; H, 6.66; N, 3.94.

*4.4.8. Methyl 4-(3,4-dimethoxyphenyl)-4-((4-methoxyphenyl)amino)butanoate (**15i**)*: Pale yellow paste; *Rf* 0.3 (hexane-ethyl acetate, 2:1); IR (neat) 1728 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.02-2.10 (m, 1H), 2.11-2.19 (m, 1H), 2.39 (t, 2H, *J*=7.2 Hz), 3.66 (s, 3H), 3.69 (s, 3H), 3.74 (brs, 1H), 3.85 (s, 3H), 3.86 (s, 3H), 4.23 (t, 1H, *J*=6.8 Hz), 6.47-6.51 (m, 2H), 6.67-6.71 (m, 2H), 6.79-6.82 (m, 1H), 6.84-6.88 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 30.8 (t), 33.1 (t), 51.5 (q), 55.5 (q), 55.6 (q), 58.2 (d), 109.3 (d), 111.0 (d), 114.47 (d), 114.52 (d), 118.3 (d), 135.7 (s), 141.3 (s), 147.8 (s), 149.0 (s), 151.8 (s),

173.8 (s); HRMS (ESI) calcd for $C_{20}H_{26}NO_5$ (M + H^+) 360.1811; found 360.1808.

*4.4.9. Methyl 4-((4-methoxyphenyl)amino)-4-(pyridin-3-yl)butanoate (**15j**)*: Pale yellow paste; *Rf* 0.35 (hexane-ethyl acetate, 1:2); ^{1}H NMR ($CDCl_3$) δ 2.06-2.20 (m, 2H), 2.45 (t, 2H, *J*=7.0 Hz), 3.67 (s, 3H), 3.69 (s, 3H), 3.99 (brs, 1H), 4.37 (t, 1H, *J*=7.0 Hz), 6.43-6.47 (m, 2H), 6.66-6.70 (m, 2H), 7.24 (dd, 1H, *J*=4.7, 8.0 Hz), 7.64-7.67 (m, 1H), 8.48-8.50 (m, 1H), 8.60 (d, 1H, *J*=1.9 Hz); ^{13}C NMR ($CDCl_3$) δ 30.8 (t), 33.0 (t), 51.8 (q), 55.6 (q), 56.3 (d), 114.6 (d), 114.8 (d), 123.6 (d), 133.9 (d), 138.7 (s), 140.7 (s), 148.6 (d), 148.7 (d), 152.2 (s), 173.7 (s); HRMS (ESI) calcd for $C_{17}H_{21}N_2O_3$ (M + H^+) 301.1552; found 301.1550.

*4.4.10. 4-(4-Chlorophenyl)-4-((4-methoxyphenyl)amino)butanenitrile (**19b**)*: Pale yellow paste; *Rf* 0.55 (hexane-ethyl acetate, 2:1); IR (neat) 3366, 2245 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.14-2.29 (m, 2H), 2.45-2.52 (m, 1H), 2.58-2.65 (m, 1H), 3.82 (s, 3H), 4.53 (t, 1H, *J*=7.1 Hz), 6.60-6.64 (m, 2H), 6.81-6.84 (m, 2H), 7.36-7.40 (m, 2H), 7.42-7.45 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.2 (t), 33.3 (t), 55.4 (q), 56.8 (d), 114.6 (d), 114.9 (d), 119.3 (s), 127.5 (d), 128.8 (d), 132.9 (s), 140.2 (s), 140.5 (s), 152.2 (s); HRMS (ESI) calcd for $C_{17}H_{18}ClN_2O$ (M + H^+) 301.1108; found 301.1105.

*4.4.11. 4-(2-Methoxyphenyl)-4-((4-methoxyphenyl)amino)butanenitrile (**19d**)*: Pale yellow paste; *Rf* 0.55 (hexane-ethyl acetate, 2:1); IR (neat) 3368, 2245 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.09-2.19 (m, 2H), 2.39-2.50 (m, 2H), 3.69 (s, 3H), 3.89 (s, 3H), 4.68 (t, 1H, *J*=6.9 Hz), 6.53-6.57 (m, 2H), 6.67-6.71 (m, 2H), 6.87-6.91 (m, 2H), 7.19-7.24 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 31.6 (t), 53.3 (d), 55.1 (q), 55.4 (q), 110.5 (d), 114.5 (d), 114.8 (d), 119.7 (s), 120.6 (d), 127.2 (d), 128.3 (d), 129.2 (s), 140.9 (s), 152.0 (s), 156.8 (s); HRMS (ESI) calcd for $C_{18}H_{21}N_2O_2$ (M + H^+) 297.1603; found 297.1601.

*4.4.12. 4-(4-Fluorophenyl)-4-((4-methoxyphenyl)amino)butanenitrile (**19e**)*: Pale yellow paste; *Rf* 0.5 (hexane-ethyl acetate, 2:1); IR (neat) 3368, 2245 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.03-2.19 (m, 2H), 2.31-2.39 (m, 1H), 2.44-2.51 (m, 1H), 3.70 (s, 3H), 4.41 (t, 1H, *J*=6.9 Hz), 6.50-6.54 (m, 2H), 6.69-6.72 (m, 2H), 7.00-7.05 (m, 2H), 7.27-7.32 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.3 (t), 33.5 (t), 55.5 (q), 56.9 (d), 114.6 (d), 115.0 (d), 115.7 (d, J_{CCF}=21.7 Hz), 119.3 (s), 127.8 (d, J_{CCCF}=7.7 Hz),

137.6 (s), 140.3 (s), 152.3 (s), 162.0 (s, J_{CF}=245.9 Hz); HRMS (ESI) calcd for $C_{17}H_{18}FN_2O$ (M + H^+) 285.1403; found 285.1400.

*4.4.13. 4-(3-Cyano-1-((4-methoxyphenyl)amino)propyl)benzonitrile (**19f**)*: Pale yellow paste; *Rf* 0.3 (hexane-ethyl acetate, 2:1); IR (neat) 3368, 2228 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.08-2.15 (m, 2H), 2.39-2.46 (m, 1H), 2.52-2.59 (m, 1H), 3.69 (s, 3H), 4.50 (t, 1H, *J*=7.0 Hz), 6.46-6.50 (m, 2H), 6.68-6.72 (m, 2H), 7.44-7.47 (m, 2H), 7.62-7.65 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 33.2 (t), 55.5 (q), 57.2 (d), 111.2 (s), 114.7 (d), 114.9 (d), 118.5 (s), 119.0 (s), 127.0 (d), 132.6 (d), 139.8 (s), 147.9 (s), 152.4 (s); HRMS (ESI) calcd for $C_{18}H_{18}N_3O$ (M + H^+) 292.1450; found 292.1447.

*4.4.14. 4-((4-Methoxyphenyl)amino)-4-(naphthalen-1-yl)butanenitrile (**19g**)*: Pale yellow paste; *Rf* 0.5 (hexane-ethyl acetate, 2:1); IR (neat) 3366, 2245 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.10-2.18 (m, 1H), 2.35-2.43 (m, 1H), 2.45-2.52 (m, 1H), 2.60-2.67 (m, 1H), 3.67 (s, 3H), 3.93 (brs, 1H), 5.29 (dd, 1H, *J*=4.7, 8.4 Hz), 6.50-6.54 (m, 2H), 6.66-6.69 (m, 2H), 7.41 (dd, 1H, *J*=7.4, 8.0 Hz), 7.51-7.56 (m, 2H), 7.59-7.63 (m, 1H), 7.78 (d, 1H, *J*=8.2 Hz), 7.90-7.94 (m, 1H), 8.17 (d, 1H, *J*=8.5 Hz); ^{13}C NMR ($CDCl_3$) δ 14.3 (t), 32.6 (t), 52.8 (d), 55.3 (q), 114.4 (d), 114.5 (d), 119.6 (s), 121.8 (d), 122.6 (d), 125.4 (d), 125.5 (d), 126.4 (d), 127.8 (d), 129.0 (d), 130.5 (s), 133.8 (s), 137.0 (s), 140.5 (s), 151.9 (s); HRMS (ESI) calcd for $C_{21}H_{21}N_2O$ (M + H^+) 317.1654; found 317.1652.

*4.4.15. 4-((4-Methoxyphenyl)amino)-4-(naphthalen-2-yl)butanenitrile (**19h**)*: White solid; *Rf* 0.55 (hexane-ethyl acetate, 2:1); mp 117-118 °C; IR (ATR) 3360, 2249 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.14-2.29 (m, 2H), 2.33-2.41 (m, 1H), 2.46-2.53 (m, 1H), 3.68 (s, 3H), 3.85 (brs, 1H), 4.59 (t, 1H, *J*=7.0 Hz), 6.56-6.60 (m, 2H), 6.67-6.71 (m, 2H), 7.42-7.51 (m, 3H), 7.78-7.79 (m, 1H), 7.80-7.86 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 14.2 (t), 33.2 (t), 55.4 (d), 57.6 (q), 114.6 (d), 114.9 (d), 119.4 (s), 123.8 (d), 125.2 (d), 125.8 (d), 126.2 (d), 127.5 (d), 127.6 (d), 128.7 (d), 132.7 (s), 133.1 (s), 139.2 (s), 140.6 (s), 152.1 (s). Anal. Calcd for $C_{21}H_{20}N_2O$: C, 79.72; H, 6.37; N, 8.85. Found: C, 79.75; H, 6.41; N, 8.80.

4.5. Typical procedure of cyclization of 15 to 16

To a solution of **15a** (75 mg, 0.25 mmol) in THF (5 mL) was added NaH (0.25 mL, 0.25 mmol)

at 25 ˚C. The mixture was refluxed for 30 min and then cooled to room temperature. After the solvent was removed *in vacuo*, the residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **16a** in 85% yield. Compounds **16a**[7] and **16c**[7] were known.

*4.5.1. 5-(4-Chlorophenyl)-1-(4-methoxyphenyl)pyrrolidin-2-one (**16b**)*: White solid; *Rf* 0.15 (hexane-ethyl acetate, 2:1); mp 123-125 °C; IR (neat) 1678 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.90-2.01 (m, 1H), 2.56-2.80 (s, 3H), 3.71 (s, 3H), 5.15 (dd, 1H, *J*=5.5, 6.4 Hz), 6.74-6.80 (m, 2H), 7.12-7.17 (m, 2H), 7.22-7.28 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 28.8 (t), 30.8 (t), 55.1 (q), 63.5 (d), 113.8 (d), 124.1 (d), 127.4 (d), 128.9 (d), 130.6 (s), 133.3 (s), 139.8 (s), 156.8 (s), 174.4 (s). Anal. Calcd for $C_{17}H_{16}ClNO_2$: C, 67.66; H, 5.34; N, 4.64. Found: C, 67.73; H, 5.37; N, 4.58.

*4.5.2. 5-(2-Methoxyphenyl)-1-(4-methoxyphenyl)pyrrolidin-2-one (**16d**)*: White solid; *Rf* 0.25 (hexane-ethyl acetate, 5:1); mp 104-106 °C; IR (neat) 1697 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.91-2.00 (m, 1H), 2.52-2.75 (m, 3H), 3.73 (s, 3H), 3.88 (s, 3H), 5.53-5.57 (m, 1H), 6.76-6.80 (m, 2H), 6.82-6.91 (m, 2H), 7.03-7.07 (m, 1H), 7.19-7.24 (m, 1H), 7.34-7.39 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 27.0 (t), 31.1 (t), 55.2 (q), 55.3 (q), 58.8 (d), 110.6 (d), 113.8 (d), 120.6 (d), 123.3 (d), 126.4 (d), 128.6 (d), 128.9 (s), 131.5 (s), 156.4 (s), 174.9 (s). Anal. Calcd for $C_{18}H_{19}NO_3$: C, 72.71; H, 6.44; N, 4.71. Found: C, 72.74; H, 6.45; N, 4.61.

*4.5.3. 5-(4-Fluorophenyl)-1-(4-methoxyphenyl)pyrrolidin-2-one (**16e**)*: White solid; *Rf* 0.15 (hexane-ethyl acetate, 2:1); mp 105-106 °C; IR (neat) 1686 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.93-2.01 (m, 1H), 2.57-2.67 (m, 2H), 2.68-2.79 (m, 1H), 3.72 (s, 3H), 5.16 (dd, 1H, *J*=5.0, 7.9 Hz), 6.76-6.80 (m, 2H), 6.95-7.01 (m, 2H), 7.15-7.20 (m, 2H), 7.21-7.25 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 29.0 (t), 30.9 (t), 55.2 (q), 63.6 (d), 113.9 (d), 115.8 (d, J_{CCF}=21.1 Hz), 124.3 (d), 127.8 (d, J_{CCCF}=8.6 Hz), 130.8 (s), 137.1 (s, J_{CCCCF}=3.8 Hz), 156.9 (s), 162.1 (s, J_{CF}=246.6 Hz), 174.5 (s). Anal. Calcd for $C_{17}H_{16}FNO_2$: C, 71.56; H, 5.65; N, 4.91. Found: C, 71.55; H, 5.60; N, 4.79.

*4.5.4. 4-(1-(4-Methoxyphenyl)-5-oxopyrrolidin-2-yl)benzonitrile (**16f**)*: Pale yellow paste; *Rf* 0.3 (hexane-ethyl acetate, 1:2); IR (neat) 2228, 1686 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.93-1.99 (m, 1H), 2.61-2.76 (s, 3H), 3.73 (s, 3H), 5.25 (dd, 1H, *J*=5.3, 7.8 Hz), 6.76-6.80 (m, 2H), 7.21-7.25 (m, 2H),

7.32-7.35 (m, 2H), 7.58-7.61 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.6 (t), 30.7 (t), 55.2 (q), 63.6 (d), 111.6 (s), 114.0 (d), 118.3 (s), 123.9 (d), 126.8 (d), 130.4 (s), 132.7 (d), 146.8 (s), 156.9 (s), 174.3 (s); HRMS (ESI) calcd for $C_{18}H_{17}N_2O_2$ (M + H^+) 293.1290; found 293.1288.

*4.5.5. 1-(4-Methoxyphenyl)-5-(naphthalen-1-yl)pyrrolidin-2-one (**16g**)*: Pale yellow paste; *Rf* 0.25 (hexane-ethyl acetate, 2:1); IR (neat) 1693 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.98-2.18 (m, 1H), 2.54-2.83 (m, 3H), 3.69 (s, 3H), 5.98 (brs, 1H), 6.72-6.76 (m, 2H), 7.29 (d, 1H, *J*=7.3Hz), 7.36 (t, 1H, *J*=7.3Hz), 7.40-7.50 (m, 2H), 7.51-7.63 (m, 2H), 7.76 (d, 1 H, *J*=8.3Hz), 7.91 (d, 1 H, *J*=8.3Hz), 8.03 (d, 1 H, *J*=8.3Hz); ^{13}C NMR ($CDCl_3$) δ 27.2 (t), 30.8 (t), 54.8 (q), 60.0 (d), 113.5 (d), 122.0 (d), 125.1 (d), 125.6 (d), 126.2 (d), 127.8 (d), 128.9 (d), 129.7 (s), 131.5 (s), 133.9 (s), 135.5 (s), 156.0 (s), 174.4 (s); HRMS (ESI) calcd for $C_{21}H_{20}NO_2$ (M + H^+) 318.1494; found 318.1492.

*4.5.6. 1-(4-Methoxyphenyl)-5-(naphthalen-2-yl)pyrrolidin-2-one (**16h**)*: White solid; *Rf* 0.35 (hexane-ethyl acetate, 1:1); mp 143-144 °C; IR (ATR) 1695, 1684, 1672 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.03-2.12 (m, 1H), 2.61-2.73 (m, 2H), 2.77-2.86 (m, 1H), 3.68 (s, 3H), 5.33 (dd, 1H, *J*=4.9, 7.6 Hz), 6.71-6.77 (m, 2H), 7.29-7.37 (m, 3H), 7.43-7.49 (m, 2H), 7.64 (s, 1H), 7.73-7.83 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 28.7 (t), 30.9 (t), 55.1 (q), 64.3 (d), 113.8 (d), 123.6 (d), 124.0 (d), 125.0 (d), 126.0 (d), 126.3 (d), 127.5 (d), 128.9 (d), 131.0 (s), 132.7 (s), 133.0 (s), 138.6 (s), 156.6 (s), 174.6 (s). Anal. Calcd for $C_{21}H_{19}NO_2$: C, 79.47; H, 6.03; N, 4.41. Found: C, 79.43; H, 6.09; N, 4.29.

*4.5.7. 5-(3,4-Dimethoxyphenyl)-1-(4-methoxyphenyl)pyrrolidin-2-one (**16i**)*: Colorless paste; *Rf* 0.3 (hexane-ethyl acetate, 1:2); IR (neat) 1686 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.96-2.04 (m, 1H), 2.55-2.65 (m, 2H), 2.69-2.79 (m, 1H), 3.72 (s, 3H), 3.81 (s, 3H), 3.82 (s, 3H), 5.11 (dd, 1H, *J*=5.0, 7.7 Hz), 6.69 (brs, 1H), 6.72-6.80 (m, 4H), 7.23-7.28 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 29.1 (t), 31.0 (t), 55.2 (q), 55.7 (q), 55.8 (q), 64.1 (d), 108.9 (d), 111.1 (d), 113.8 (d), 118.5 (d), 124.3 (d), 131.0 (s), 133.7 (s), 148.4 (s), 149.3 (s), 156.8 (s), 174.6 (s); HRMS (ESI) calcd for $C_{19}H_{22}NO_4$ (M + H^+) 328.1549; found 328.1546.

*4.5.8. 1-(4-Methoxyphenyl)-5-(pyridin-3-yl)pyrrolidin-2-one (**16j**)*: Pale yellow solid; *Rf* 0.3 ethyl acetate-ethanol, 10:1); mp 73-75 °C; IR (neat) 1701, 1678 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.96-2.05 (m,

1H), 2.62-2.81 (m, 3H), 3.72 (s, 3H), 5.23 (t, 1H, *J*=6.2 Hz), 6.76-6.80 (m, 2H), 7.20-7.26 (m, 3H), 7.50-7.54 (m, 1H), 8.48-8.50 (m, 1H), 8.52 (d, 1H, *J*=1.9 Hz); ^{13}C NMR ($CDCl_3$) δ 28.8 (t), 30.9 (t), 55.3 (q), 61.9 (d), 114.1 (d), 123.8 (d), 124.5 (d), 130.3 (s), 133.7 (d), 136.8 (s), 148.2 (d), 149.2 (d), 157.1 (s), 174.4 (s). Anal. Calcd for $C_{16}H_{16}N_2O_2$: C, 71.62; H, 6.01; N, 10.44. Found: C, 71.65; H, 6.03; N, 10.38.

4.6. Typical procedure of oxidation of 16 to 17

To a solution of **16a** (53 mg, 0.2 mmol) in CH_3CN (5 mL) was added an aqueous solution (3 mL) of CAN (241 mg, 0.44 mmol) at 5 ˚C. After being stirred for 30 min at this temperature, the mixture was diluted with H_2O (20 mL) and extracted with ethyl acetate (20 mL x 3). After the solvent was removed *in vacuo*, the residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **17a** in 85% yield. Compounds **17a**,[18] **17b**,[18] **17c**,[18] **17d**,[19] **17e**,[19] and **17j**[20] were known.

*4.6.1. 4-(5-Oxopyrrolidin-2-yl)benzonitrile (**17f**)*: White solid; *Rf* 0.5 ethyl acetate-ethanol, 10:1); white solid; mp 166-167 °C; IR (neat) 3161, 2232, 1686, 1655 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.90-1.99 (m, 1H), 2.40-2.53 (m, 2H), 2.61-2.69 (m, 1H), 4.82 (t, 1H, *J*=7.3 Hz), 6.04 (brs, 1H), 7.41-7.45 (m, 2H), 7.66-7.70 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 30.1 (t), 30.8 (t), 57.7 (d), 111.7 (s), 118.4 (s), 126.3 (d), 132.7 (d), 147.9 (s), 179.0 (s). Anal. Calcd for $C_{11}H_{10}N_2O$: C, 70.95; H, 5.41; N, 15.04. Found: C, 71.01; H, 5.45; N, 14.94.

*4.6.2. 5-(Naphthalen-1-yl)pyrrolidin-2-one (**17g**)*: White solid; *Rf* 0.25 (hexane-ethyl acetate, 1:2); mp 149-151 °C; IR (neat) 3177, 1690 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.03-2.11 (m, 1H), 2.40-2.51 (m, 2H), 2.79-2.87 (m, 1H), 5.55 (dd, 1H, *J*=5.5, 7.8 Hz), 6.31 (brs, 1H), 7.47 (t, 1H, *J*=7.3Hz), 7.51-7.58 (m, 3H), 7.81 (d, 1H, *J*=7.8 Hz), 7.89-7.92 (m, 1H), 7.95 (d, 1H, *J*=8.3Hz); ^{13}C NMR ($CDCl_3$) δ 29.65 (t), 29.72 (t), 54.4 (d), 121.1 (d), 122.4 (d), 125.4 (d), 125.7 (d), 126.2 (d), 127.9 (d), 128.9 (s), 129.9 (s), 133.8 (s), 138.1 (s), 179.2 (s). Anal. Calcd for $C_{14}H_{13}NO$: C, 79.59; H, 6.20; N, 6.63. Found: C, 79.56; H, 6.22; N, 6.57.

*4.6.3. 5-(Naphthalen-2-yl)pyrrolidin-2-one (**17h**)*: White solid; *Rf* 0.3 (hexane-ethyl acetate, 1:2);

mp 183-184 °C; IR (ATR) 3179, 1686 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.03-2.12 (m, 1H), 2.43-2.58 (m, 2H), 2.62-2.70 (m, 1H), 4.93 (t, 1H, *J*=7.2 Hz), 5.97 (brs, 1H), 7.39-7.43 (m, 1H), 7.47-7.54 (m, 2H), 7.74 (s, 1H), 7.81-7.89 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 30.2 (t), 31.0 (t), 58.1 (d), 123.6 (d), 124.2 (d), 126.1 (d), 126.5 (d), 127.7 (d), 127.8 (d), 128.9 (d), 132.9 (s), 133.2 (s), 139.8 (s), 178.6 (s). Anal. Calcd for $C_{14}H_{13}NO$: C, 79.59; H, 6.20; N, 6.63. Found: C, 79.61; H, 6.24; N, 6.55.

*4.6.4. 5-(3,4-Dimethoxyphenyl)pyrrolidin-2-one (**17i**)*: Colorless paste; *Rf* 0.15 (hexane-ethyl acetate, 1:5); ^1H NMR ($CDCl_3$) δ 1.92-2.00 (m, 1H), 2.37-2.58 (m, 3H), 3.87 (s, 3H), 3.88 (s, 3H), 4.70 (t, 1H, *J*=7.3 Hz), 6.45 (brs, 1H), 6.80 (s, 1H), 6.84 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 30.4 (t), 31.4 (t), 55.9 (q), 56.0 (q), 57.9 (d), 108.5 (d), 111.2 (d), 117.8 (d), 134.8 (s), 148.6 (s), 149.3 (s), 178.5 (s); HRMS (ESI) calcd for $C_{12}H_{15}NO_3$ ($M + H^+$) 222.1130; found 222.1128.

4.7. Typical procedure of transformation of 15 to 18

To a solution of **15a** (75 mg, 0.25 mmol) in CH_3CN (5 mL) was added an aqueous solution (3 mL) of CAN (302 mg, 0.55 mmol) at 5 ˚C. The mixture was stirred for 30 min at this temperature and then neutralized with sat. $NaHCO_3$ aq. To the mixture were added $Na_2S_2O_3/5H_2O$ (62 mg, 0.25 mmol), $(Boc)_2O$ (164 mg. 0.75 mmol), and $NaHCO_3$ (63 mg, 0.75 mmol). After being stirred for 1 h at 25 ˚C, the mixture was extracted with ethyl acetate (20 mL x 3). After the solvent was removed *in vacuo*, the residue was purified by column chromatography on silica gel (hexanes-EtOAc) to give **18a** in 70% yield. Compounds **18f**[21] and **20a**[7] were known.

*4.7.1. Methyl 4-((tert-butoxycarbonyl)amino)-4-phenylbutanoate (**18a**)*: White solid; *Rf* 0.3 (hexane-ethyl acetate, 5:1); mp 81-82 °C; IR (ATR) 3385, 1732, 1684 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.41 (brs, 9H), 2.00-2.16 (m, 2H), 2.28-2.43 (m, 2H), 3.66 (s, 3H), 4.60-4.70 (m, 1H), 4.91 (brs, 1H), 7.24-7.29 (m, 3H), 7.32-7.36 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.1 (q), 30.8 (t), 31.5 (t), 51.4 (q), 54.2 (d), 79.1 (s), 126.1 (d), 127.1 (d), 128.4 (d), 142.0 (s), 155.1 (s), 173.5 (s). Anal. Calcd for $C_{16}H_{23}NO_4$: C, 65.51; H, 7.90; N, 4.77. Found: C, 65.56; H, 7.90; N, 4.65.

*4.7.2. Methyl 4-((tert-butoxycarbonyl)amino)-4-(4-chlorophenyl)butanoate (**18b**)*: White solid; *Rf* 0.3 (hexane-ethyl acetate, 5:1); mp 110-112 °C; IR (ATR) 3389, 1730, 1684 cm^{-1}; ^1H NMR ($CDCl_3$)

δ 1.41 (brs, 9H), 1.96-2.12 (m, 2H), 2.29-2.42 (m, 2H), 3.67 (s, 3H), 4.56-4.69 (m, 1H), 4.93 (brs, 1H), 7.19-7.23 (m, 2H), 7.29-7.32 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.3 (q), 30.7 (t), 31.3 (t), 51.6 (q), 53.7 (d), 79.4 (s), 127.5 (d), 128.6 (d), 132.8 (s), 140.8 (s), 155.1 (s), 173.5 (s). Anal. Calcd for $C_{16}H_{22}ClNO_4$: C, 58.63; H, 6.76; N, 4.27. Found: C, 58.65; H, 6.77; N, 4.20.

*4.7.3. Methyl 4-((tert-butoxycarbonyl)amino)-4-(4-methoxyphenyl)butanoate (**18c**)*: White solid; *Rf* 0.3 (hexane-ethyl acetate, 5:1); mp 94-95 °C; IR (ATR) 3374, 1732, 1682 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.41 (brs, 9H), 1.97-2.17 (m, 2H), 2.26-2.41 (m, 2H), 3.65 (s, 3H), 3.79 (s, 3H), 4.53-4.65 (m, 1H), 4.84 (brs, 1H), 6.85-6.88 (m, 2H), 7.17-7.22 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.3 (q), 31.0 (t), 31.7 (t), 51.7 (q), 53.9 (d), 55.3 (q), 79.4 (s), 114.0 (d), 127.4 (d), 134.1 (s), 155.20 (s), 158.8 (s), 173.7 (s). Anal. Calcd for $C_{17}H_{25}NO_5$: C, 63.14; H, 7.79; N, 4.33. Found: C, 63.12; H, 7.83; N, 4.29.

*4.7.4. Methyl 4-((tert-butoxycarbonyl)amino)-4-(2-methoxyphenyl)butanoate (**18d**)*: Colorless Paste; *Rf* 0.3 (hexane-ethyl acetate, 5:1); IR (ATR) 3368, 1732, 1688, 1678 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.41 (brs, 9H), 1.97-2.17 (m, 2H), 2.26-2.41 (m, 2H), 3.65 (s, 3H), 3.79 (s, 3H), 4.53-4.65 (m, 1H), 4.84 (brs, 1H), 6.85-6.88 (m, 2H), 7.17-7.22 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.3 (q), 31.0 (t), 31.7 (t), 51.7 (q), 53.9 (d), 55.3 (q), 79.4 (s), 114.0 (d), 127.4 (d), 134.1 (s), 155.20 (s), 158.8 (s), 173.7 (s); HRMS (ESI) calcd for $C_{17}H_{26}NO_5$ (M + H$^+$) 324.1811; found 324.1809.

*4.7.5. Methyl 4-((tert-butoxycarbonyl)amino)-4-(4-fluorophenyl)butanoate (**18e**)*: Colorless Paste; *Rf* 0.3 (hexane-ethyl acetate, 5:1); IR (ATR) 3379, 1732, 1682 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.41 (brs, 9H), 1.96-2.15 (m, 2H), 2.27-2.43 (m, 2H), 3.66 (s, 3H), 4.58-4.69 (m, 1H), 5.12 (brs, 1H), 6.98-7.04 (m, 2H), 7.22-7.27 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 28.2 (q), 30.8 (t), 31.5 (t), 51.6 (q), 53.7 (d), 79.5 (s), 115.4 (d, J_{CCF}=21.6 Hz), 127.8 (d, J_{CCCF}=8.1 Hz), 138.0 (s), 155.1 (s), 161.9 (s, J_{CF}=245.0 Hz), 173.6 (s); HRMS (ESI) calcd for $C_{16}H_{23}FNO_4$ (M + H$^+$) 312.1611; found 312.1608

*4.7.6. Methyl 4-((tert-butoxycarbonyl)amino)-4-(naphthalen-1-yl)butanoate (**18g**)*: White solid; *Rf* 0.25 (hexane-ethyl acetate, 5:1); mp 128-130 °C; IR (ATR) 3331, 1730, 1684 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.43 (brs, 9H), 2.17-2.38 (m, 2H), 2.42-2.54 (m, 2H), 3.68 (s, 3H), 5.01 (brs, 1H), 5.49-5.57 (m, 1H), 7.45-7.47 (m, 2H), 7.48-7.52 (m, 1H), 7.53-7.57 (m, 1H), 7.76-7.80 (m, 1H),

7.87 (d, 1H, *J*=8.0Hz), 8.17 (d, 1H, *J*=8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 28.2 (q), 30.9 (t), 33.4 (t), 49.8 (d), 51.5 (q), 79.3 (s), 122.4 (d), 123.0 (d), 125.1 (d), 125.6 (d), 126.3 (d), 127.9 (d), 128.7 (d), 130.8 (s), 133.8 (s), 137.9 (s), 155.2 (s), 173.6 (s). Anal. Calcd for $C_{20}H_{25}NO_4$: C, 69.95; H, 7.34; N, 4.08. Found: C, 69.95; H, 7.39; N, 4.05.

*4.7.7. Methyl 4-((tert-butoxycarbonyl)amino)-4-(naphthalen-2-yl)butanoate (**18h**)*: White solid; *Rf* 0.25 (hexane-ethyl acetate, 5:1); mp 122-123 °C; IR (ATR) 3377, 1730, 1716, 1686 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.42 (brs, 9H), 2.11-2.25 (m, 2H), 2.31-2.46 (m, 2H), 3.65 (s, 3H), 4.75-4.88 (m, 1H), 5.01 (brs, 1H), 7.37-7.42 (m, 1H), 7.44-7.50 (m, 2H), 7.72 (brs, 1H), 7.79-7.85 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 28.2 (q), 30.9 (t), 31.4 (t), 51.5 (q), 54.3 (d), 79.3 (s), 124.3 (d), 124.9 (d), 125.6 (d), 126.0 (d), 127.4 (d), 127.7 (d), 128.4 (d), 132.6 (s), 133.1 (s), 139.4 (s), 155.2 (s), 173.5 (s). Anal. Calcd for $C_{20}H_{25}NO_4$: C, 69.95; H, 7.34; N, 4.08. Found: C, 69.89; H, 7.35; N, 3.98.

*4.7.8. tert-Butyl (3-cyano-1-(4-chlorophenyl)propyl)carbamate (**20b**)*: White solid; *Rf* 0.5 (hexane-ethyl acetate, 2:1); mp 130-132 °C; IR (ATR) 3385, 2243, 1688, 1678 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.42 (brs, 9H), 2.01-2.24 (m, 2H), 2.30-2.41 (m, 2H), 4.63-4.74 (m, 1H), 4.81 (d, 1H, *J*=8.0 Hz), 7.20-7.23 (m, 2H), 7.33-7.36 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 28.2 (q), 32.0 (t), 53.4 (d), 80.1 (s), 118.9 (s), 127.6 (d), 129.0 (d), 133.6 (s), 139.2 (s), 155.1 (s). Anal. Calcd for $C_{15}H_{19}ClN_2O_2$: C, 61.12; H, 6.50; N, 9.50. Found: C, 61.18; H, 6.54; N, 9.37.

*4.7.9. tert-Butyl (3-cyano-1-(4-methoxyphenyl)propyl)carbamate (**20c**)*: White solid; *Rf* 0.4 (hexane-ethyl acetate, 2:1); mp 133-134 °C; IR (ATR) 3387, 2247, 1682 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.43 (brs, 9H), 2.01-2.11 (m, 1H), 2.16-2.27 (m, 1H), 2.27-2.35 (m, 2H), 3.81 (s, 3H), 4.58-4.67 (m, 1H), 4.75 (brs, 1H), 6.88-6.91 (m, 2H), 7.17-7.21 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 28.2 (q), 32.2 (t), 53.5 (d), 55.2 (q), 79.9 (s), 114.3 (d), 119.2 (s), 127.5 (d), 132.4 (s), 155.2 (s), 159.2 (s). Anal. Calcd for $C_{16}H_{22}N_2O_3$: C, 66.18; H, 7.64; N, 9.65. Found: C, 66.26; H, 7.66; N, 9.53.

*4.7.10. tert-Butyl (3-cyano-1-(2-methoxyphenyl)propyl)carbamate (**20d**)*: White solid; *Rf* 0.5 (hexane-ethyl acetate, 2:1); mp 125-126 °C; IR (ATR) 3377, 2247, 1682 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.43 (brs, 9H), 2.05-2.40 (m, 4H), 3.88 (s, 3H), 4.77-4.84 (m, 1H), 5.52 (d, 1H, *J*=8.9 Hz),

6.89-6.96 (m, 2H), 7.15-7.19 (m, 1H), 7.26-7.31 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 14.6 (t), 28.2 (q), 31.3 (t), 52.7 (d), 55.3 (q), 79.6 (s), 110.0 (d), 119.5 (s), 121.0 (d), 127.8 (s), 128.7 (d), 129.1 (d), 155.3 (s), 156.9 (s). Anal. Calcd for $C_{16}H_{22}N_2O_3$: C, 66.18; H, 7.64; N, 9.65. Found: C, 66.20; H, 7.65; N, 9.57.

*4.7.11. tert-Butyl (3-cyano-1-(4-fluorophenyl)propyl)carbamate (**20e**)*: White solid; *Rf* 0.45 (hexane-ethyl acetate, 2:1); mp 124-125 °C; IR (ATR) 3379, 2247, 1680 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.42 (brs, 9H), 2.02-2.26 (m, 2H), 2.32-2.39 (m, 2H), 4.63-4.73 (m, 1H), 4.80 (brs, 1H), 7.04-7.09 (m, 2H), 7.23-7.28 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 28.2 (q), 32.2 (t), 53.4 (d), 80.1 (s), 115.8 (d, J_{CCF}=22.8 Hz), 119.0 (s), 127.9 (d, J_{CCCF}=7.2 Hz), 136.4 (s), 155.1 (s), 162.2 (s, J_{CF}=247.1 Hz). Anal. Calcd for $C_{15}H_{19}FN_2O_2$: C, 64.73; H, 6.88; N, 10.07. Found: C, 64.77; H, 6.92; N, 9.98.

*4.7.12. tert-Butyl (3-cyano-1-(4-cyanophenyl)propyl)carbamate (**20f**)*: Pale yellow paste; *Rf* 0.3 (hexane-ethyl acetate, 2:1); IR (ATR) 3348. 2230, 1686 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.44 (brs, 9H), 2.03-2.20 (m, 2H), 2.36-2.50 (m, 2H), 4.71-4.84 (m, 1H), 5.14 (brs, 1H), 7.40-7.45 (m, 2H), 7.65-7.70 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 28.1 (q), 31.8 (t), 53.7 (d), 80.4 (s), 111.7 (s), 118.4 (s), 118.7 (d), 126.9 (d), 132.7 (d), 146.3 (s), 155.0 (s); HRMS (ESI) calcd for $C_{16}H_{20}N_3O_2$ ($M + H^+$) 286.1556; found 286.1553.

*4.7.13. tert-Butyl (3-cyano-1-(naphthalen-1-yl)propyl)carbamate (**20g**)*: White solid; *Rf* 0.5 (hexane-ethyl acetate, 2:1); mp 147-149 °C; IR (ATR) 3381, 2251, 1680 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.44 (brs, 9H), 2.33-2.41 (m, 2H), 2.46-2.53 (m, 2H), 4.91 (brs, 1H), 5.54 (d, 1H, *J*=7.4 Hz), 7.41-7.45 (m, 1H), 7.47 (t, 1H, *J*=7.8 Hz), 7.51-7.55 (m, 1H), 7.56-7.60 (m, 1H), 7.83 (d, 1H, *J*= 8.0 Hz), 7.90 (d, 1H, *J*=7.8 Hz), 8.11 (d, 1H, *J*=8.4 Hz); ^{13}C NMR ($CDCl_3$) δ 14.4 (t), 28.0 (q), 31.7 (t), 49.5 (d), 79.2 (s), 119.3 (s), 122.6 (d), 125.1 (s), 125.8 (d), 126.5 (d), 128.4 (d), 128.8 (d), 130.5 (s), 133.7 (s), 136.5 (s), 155.3 (s). Anal. Calcd for $C_{19}H_{22}N_2O_2$: C, 73.52; H, 7.14; N, 9.03. Found: C, 73.59; H, 7.21; N, 8.94.

*4.7.14. tert-Butyl (3-cyano-1-(naphthalen-2-yl)propyl)carbamate (**20h**)*: White solid; *Rf* 0.5 (hexane-ethyl acetate, 2:1); mp 138-139 °C; IR (ATR) 3391, 2249, 1684 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ

1.43 (brs, 9H), 2.15-2.41 (m, 4H), 4.81-4.93 (m, 1H), 4.93 (brs, 1H), 7.36-7.40 (m, 1H), 7.48-7.54 (m, 2H), 7.73 (brs, 1H), 7.81-7.89 (m, 3H); ^{13}C NMR ($CDCl_3$) δ 14.3 (t), 28.2 (q), 32.0 (t), 54.1 (d), 79.9 (s), 119.1 (s), 123.9 (d), 125.2 (s), 126.1 (d), 126.4 (d), 127.5 (d), 127.8 (d), 128.9 (d), 132.8 (s), 133.1 (s), 137.7 (s), 155.2 (s). Anal. Calcd for $C_{19}H_{22}N_2O_2$: C, 73.52; H, 7.14; N, 9.03. Found: C, 73.56; H, 7.19; N, 8.97.

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