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Effective Synthesis of Photoreactive Homophenylalanine and Aroylalanine

Effective Synthesis of Optically Active Trifluoromethylidiazirinyl Homophenylalanine and Aroylalanine Derivatives with Friedel-Crafts Reactions in Triflic Acid.

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Abstract

Effective Friedel-Crafts reactions with 3-(3-methoxyphenyl)-3-(trifluoromethyl)-3H-diazirine and optically active N-TFA-Asp(Cl)-OMe in triflic acid afforded homophenylalanine derivatives effectively without loss of the optical purity.

Key words:

diazirine; photoaffinity labeling; Friedel-Crafts reaction; triflic acid;
Introduction

Photoaffinity labeling is a useful biochemical method in the investigations of structural and functional relationships between small biologically active compounds and biomolecules, such as enzymes, RNA, and DNA. Various photophores, such as phenyldiazirine, arylazide and benzophenone, have been developed as the photophores. It would be ideal because we can furnish photolabeling groups with minimum structural alteration. It has been also established that (3-trifluoromethyl)phenyldiazirinyl function can be selectively activated without giving damages to peptides and proteins by irradiating at 350nm. But it usually requires not only steps of manipulations to introduce photophores into the target molecules, but also independent construction of the (3-trifluoromethyl)phenyldiazirinyl groups. These encouraged us in establishing effective protocol to furnish the (3-trifluoromethyl)phenyldiazirinyl photophore. It was expected that amino acid derivatives carrying photolabeling group would become powerful tool in the mechanistic investigations of biologically active peptides, and in studying their metabolic pathways.

We focused on developing the (3-trifluoromethyl)diazirinyl photophore into homophenylalanine (hPhe), since interesting biological behaviors have been discovered by replacing a phenylalanine in biological peptides with hPhe and also reported as a starting material for pharmaceutical products such as benazepril and enarapril, both of which inhibit angiotensin converting enzyme (ACE). Efficient synthesis of photoactivatable optically pure hPhe is important. Although several synthetic protocols for optically active hPhe have been reported with various methodologies including enzymatic resolution, Suzuki-coupling, diastereoselective Michael addition and catalytic asymmetric hydrogenation, these required the
special reagents or precursors. It might not be suitable to apply those for
preparation of diazirinylated hPhe because some conditions might decline
the diazirine function. In this paper, we would like to report an effective
method providing optically active diazirinyl hPhe with featuring
Friedel-Crafts (F-C) reactions with
3-(3-methoxyphenyl)-3-(trifluoromethyl)-3H-diazirine 1\textsuperscript{(12)} and β-acid chloride
of aspartic acid 2\textsuperscript{(13)} as key steps.

Results and Discussion

We chose β-acid chloride form of N-trifluoromethyl (S)-aspartic acid
α-methyl ester 2 as the electrophilic precursor. When we first attempted the
reaction between 1 and 2 at room temperature employing aluminium
chloride as the activator, however, the desired reaction did not proceed and
both 1 and 2 were recovered in CH\textsubscript{2}Cl\textsubscript{2} or CH\textsubscript{3}NO\textsubscript{2}. (Fig.1, Run 1 and 2) The
reflux conditions led decomposition of 2. (Fig.1, Run 3 and 4) Although F-C
reactions between N- aspartic anhydride derivatives and aromatics have
been reported\textsuperscript{,14-19)} the aromatics had to be employed excess amounts as the
solvents. It would be preferable if we could use stoichiometric amounts of
aromatics in the process by taking account of not only operational feasibility
as well as economic matters. The reaction did not proceed by employing
titanium chloride, which had been effective for formylation\textsuperscript{20)} as the activator
in CH\textsubscript{2}Cl\textsubscript{2} or neat conditions. (Fig.1, Run 5 and 6) It was found that the
desired reaction smoothly proceeded at 0 °C to give the adduct 3 and 4 in
over 87% by employing stoichiometric amounts of 1, when
trifluoromethanesulfonic acid (TfOH) was employed as the solvent. The
suspension at the initial stage became clear solution upon the onset of the
reaction. The regioisomer 3 and 4 were readily separated by silica gel column
chromatography. The NOESY spectrum of major product 3 gave the
correlation signals between C'2 OCH3 and C'3 H, which disclosed the
substitution pattern. In the case of minor product 4, NOESY correlation
was obtained C'4 OCH3 and both C'3 and C'5 H. (R)-2 was also reacted with 1
in the same condition to afford (R)-3 and 4 in good yield. (Fig.1, Run 7)
Notably the higher temperature afforded complexed mixture because the
decomposition of 1 and 2. (Fig.1, Run 8) These results were consistent with
the report that diazirinyl N·N double bond was easily decomposed in the
presence of Lewis acid over 25 °C. Unfortunately,
3'-phenyl-3-(3-trifluoromethyl)-3H-diazirine, which has no activating
methoxy substituent on benzene ring, did not react with (S)- or (R)-2 in
TfOH at 0°C. Higher temperature decomposed the diazirinyl ring at higher
temperatures. We have already reported that the
3'-phenyl-3-(3-trifluoromethyl)-3H-diazirine easily reacted with
dichloromethyl methyl ether to give formylation product in TfOH. These
results indicated that the reactivity of both acyl donor and acyl acceptor also
plays a critical role. Furthermore, trifluoromethyldiazirinyl moiety plays
slightly as the electron withdrawing group for nucleophilic substitution of
aromatic compounds.

As the adduct 3 and 4 in hand, the newly introduced carbonyl group
was then reduced to a hPhe derivative. It has already been reported that the
diazirinyl N·N double bond was labile under H2-Pd/C conditions. We found
selective reduction of benzylic carbonyl to methylene could be performed
with triethylsilane / TFA system to give 5 in good yield. No decomposition
of the diazirinyl ring was observed during the reduction. Finally
deprotections of (S)- and (R)-5 were performed using an alkaline condition to
afford diazirinyl hPhe 6 in good yield (90%). However, the conditions
decomposed to result complex mixture when aroyl derivative 3 was employed.
Deprotection of 3 could be achieved by treating with 6N HCl in acetic acid at
80 °C, affording 7 (Scheme 1).

Scheme 1

The enantiopurities of compounds 6 and 7 were determined with chiral
HPLC (CHIROBIOTIC T, Astec) which revealed these were >98% ee to
prove no racemization during the synthesis. (Fig. 2)

Figure 2

Photolysise properties of diazirinyl compounds were examined with
black light (15W). We have already demonstrated that the concentration of
diazirinyl compound was to be set less than 1 mM to minimize the
isomerization to the diazo compound. Maximum absorptions at 360 nm for
6 and 7 were decreased upon irradiation times (Fig.3). The half-life of 6 and 7
was determined to be 8.5 and 3.2 min, respectively based on the intensity at
360 nm. We concluded the values are fast enough for photoaffinity labeling.

Figure 3

In these studies we have developed effective synthesis of photoreactive
and enantiomerically pure hPhe and 2-methoxybenzoylalanine from
3-(3-methoxyphenyl)-3-(trifluoromethyl)-3H-diazirin and (S) and (R)
aspartic acid derivative as the effective photolabeling probe without
racemization. The key F-C reaction proceeded by employing
trifluoromethanesulfonic acid as the solvent. The following silane promoted
reduction took place the transformation the benzylic carbonyl to methylene.
The results will be contributed to the studies in structure-activity
relationships for the side chain of aromatic α-amino acids.

Experimental

General methods. Optical rotation values were measured by a JASCO
DIP-370 polarimeter. IR spectra were measured by a JASCO FTIR-4100. 1H-, 13C- and 19F- NMR spectra were measured by a JEOL ECA 500 spectrometer.
In the 1H-NMR spectra, the chemical shifts are expressed in ppm downfield
from the signal for tetramethylsilane used as an internal standard. Splitting
patterns are designated as s (singlet), d (doublet), t (triplet), and m
(multiplet). In the 13C-NMR spectra, the 13C chemical shifts of the solvents
were used as the internal standard (13CDCl3 77.0ppm; or 13CD3OD, 49.5ppm).
In the 19F-NMR spectra, the chemical shifts are reported with default
values without correction. MS spectra were obtained with a Hitachi
NanoFrontier LD mass spectrometer. Chiral HPLCs were performed with
CHIROBIOTIC T (Astec) 4.6 x 250 mm, eluted with 10% EtOH – H2O; flow
rate 1.0 ml/min; UV detection at 210 nm.

(S)-Methyl 4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl) phenyl)-4-oxo-2-(2,2,2-trifluoroacetamido)butanoate ((S)-3) and (S)-methyl
4-(4-methoxy-2-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)-4-oxo-
2-(2,2,2-trifluoroacetamido)butanoate ((S)-4)

Compound 112 (24.7 mg, 0.11 mmol) and (S)- 213 (29.0 mg, 0.11 mmol)
were dissolved in TfOH (0.25 ml, 2.9 mmol) at 0 °C. The yellow reaction
mixture was stirred for two hours at the same temperature, then poured into
cold water and AcOEt (30 : 30 ml). The organic layer was washed with
aqueous 1M HCl, saturated NaHCO₃, 1N HCl and saturated NaCl, then
dried over MgSO₄, and filtered. The filtrate was concentrated, the residue
was subjected to silica chromatography (AcOEt : n-hexane = 1 : 5) to afford
pure (S)-3 (34.4 mg, 71%) and (S)-4 (13.6 mg, 28%) as a pale yellow oil.
(S)-3: [α]D +77° (c 1.0, CHCl₃); IR (film) cm⁻¹: 3330, 1720, 1675, 1610;
1H-NMR (CDCl₃) δ: 7.79 (1H, d, J = 8.0 Hz), 7.54 (1H, brd, J = 8.0 Hz), 6.80
(1H, d, J = 8.0 Hz), 6.66 (1H, s), 4.89-4.86 (1H, m), 3.91 (3H, s), 3.78 (1H, dd,
J = 19.2, 4.3 Hz), 3.73 (3H, s), 3.57 (1H, dd, J = 18.9, 4.0 Hz); 13C-NMR
(CDCl₃) δ: 197.34, 170.12, 159.47, 156.91 (q, 2JCF = 37.6 Hz), 136.06, 131.46,
126.42, 121.77 (q, 1JCF = 274.7 Hz), 118.80, 115.63 (q, 1JCF = 287.9 Hz), 109.63,
55.85, 53.15, 48.92, 45.29, 38.45 (q, 2JCF = 40.4 Hz); 19F-NMR (CDCl₃) δ:
-63.18, -74.34; ESI-MS m/z: 442 (M+H)+, ESI-HRMS: calcd. for C₁₆H₁₄F₆N₄O₅
(M+H)+, 442.0832; found, m/z 442.0826.
(S)-4: [α]D +57° (c 1.0, CHCl₃); IR (film) cm⁻¹: 3330, 1725, 1690, 1610;
1H-NMR (CDCl₃) δ: 7.82 (1H, d, J = 8.6 Hz), 7.63 (1H, brd, J = 7.4 Hz), 7.19
(1H, s), 7.02 (1H, d, J = 8.6 Hz), 4.97-4.94 (1H, m), 3.91 (3H, s), 3.86-3.82 (4H,
m), 3.56 (1H, dd, J = 18.3, 3.4 Hz); 13C-NMR (CDCl₃) δ: 196.22, 169.70,
163.71, 157.05 (q, 2JCF = 38.0 Hz), 132.51, 130.09, 129.53, 121.62 (q, 1JCF =
275.1 Hz), 117.60, 115.56 (q, 1JCF = 287.5 Hz), 115.20, 55.87, 53.25, 48.71,
40.81, 29.22 (q, 2JCF = 40.0 Hz); 19F-NMR (CDCl₃) δ: -66.75, -72.86; ESI-MS
m/z: 442 (M+H)+, ESI-HRMS: calcd. for C₁₆H₁₄F₆N₄O₅ (M+H)+, 442.0832;
found, m/z 442.0828.
(R)-Methyl 4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl)
phenyl)-4-oxo-2-(2,2,2-trifluoroacetamido)butanoate ((R)-3) and (R)-methyl
4-(4-methoxy-2-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)-4-oxo-
2-(2,2,2-trifluoroacetamido)butanoate ((R)-4)
The same treatment of 1 (24.7 mg, 0.11 mmol) and (R)-2 (29.0 mg, 0.11
mmol) as described in above gave \((R)-3\) (33.0 mg, 68%) and \((R)-4\) (9.2 mg, 19%) as yellow oil. The \(^1\)H-, \(^{13}\)C- NMR and IR of these samples were identical to these record for \((S)-3\) and 4.

\((R)-3\) \([\alpha]_D -76^\circ\) (c 1.0, CHCl\(_3\)); \((R)-4\) \([\alpha]_D -58^\circ\) (c 1.0, CHCl\(_3\))

\((S)\)-Methyl 4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl) phenyl)-2-(2,2,2-trifluoroacetamido)butanoate ((S)-5)

To a solution of \((S)-3\) (169 mg, 0.38 mmol) in TFA (1.5 ml, 20 mmol), \(\text{Et}_3\text{SiH}\) (0.30 ml, 1.9 mmol) was added dropwise. The reaction mixture was stirred for two hours, and partitioned with AcOEt (80 ml). The organic layer was washed with saturated NaHCO\(_3\), 1N HCl and saturated NaCl, then dried over MgSO\(_4\) and filtered. After the filtrate was concentrated, the residue was subjected to silica chromatography (AcOEt : n-hexane = 1 : 10) to afford a colorless amorphous mass (115 mg, 76%).

\([\alpha]_D +65^\circ\) (c 1.0, CHCl\(_3\)); IR (film) cm\(^{-1}\) : 3320, 1720, 1610; \(^1\)H-NMR (CDCl\(_3\)) \(\delta\) : 7.11 (1H, d, \(J = 7.4\) Hz), 7.04 (1H, d, \(J = 7.4\) Hz), 6.74 (1H, brd, \(J = 6.9\) Hz), 6.57 (1H, s), 4.64-4.62 (1H, m), 3.81 (1H, s), 3.68 (1H, s), 2.64 (2H, t, \(J = 7.7\) Hz), 2.25-2.22 (1H, m), 2.10-2.03 (1H, m); \(^{13}\)C-NMR (CDCl\(_3\)) \(\delta\) : 171.00, 157.40, 156.74 (q, \(2J_{CF} = 37.2\) Hz), 130.41, 130.21, 128.69, 122.07 (q, \(1J_{CF} = 19274.3\) Hz), 118.90 , 115.63 (q, \(1J_{CF} = 287.5\) Hz), 108.12 , 55.24, 52.65, 52.18, 31.03, 28.37 (q, \(2J_{CF} = 40.0\) Hz), 25.32; \(^{19}\)F-NMR (CDCl\(_3\)) \(\delta\) : -66.54, -75.28.

ESI-MS \(m/z\) 400 (M-N\(_2\)+H\(^+\)), ESI-HRMS: calcd. for C\(_{16}\)H\(_{16}\)F\(_6\)NO\(_4\) (M-N\(_2\)+H\(^+\)), 400.0978; found, \(m/z\) 400.0989.

\((R)-\) Methyl 4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl) phenyl)-2-(2,2,2-trifluoroacetamido)butanoate ((R)-5)

The same treatment of \((R)-3\) (168 mg, 0.38 mmol) as described in above gave \((R)-5\) (121 mg, 80%) as yellow oil. The \(^1\)H-, \(^{13}\)C- NMR and IR of these
samples were identical to these record for (S)-5.

[α]D -65° (c 1.0, CHCl3).

(S)-2-amino-4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)butanoic acid ((S)-6)

To a solution of (S)-4 (26.4 mg, 60 µmol) in MeOH (6.0 ml), 1N NaOH (0.50 ml) was added at room temperature. After stirring for 1 hour, silica gel (2 g) was added. The resulting mixture was then evaporated. The residue was subjected to silica chromatography (CH2Cl2 : MeOH : H2O : acetic acid = 9 : 2 : 0.25 : 0.05) to afford a colorless solid (17.3 mg, 91%).

[α]D -15° (c 2.0, MeOH); IR (film) cm⁻¹ : 2950, 1680; 1H-NMR (CD3OD) δ: 7.22 (1H, d, J = 7.4 Hz), 6.79 (1H, d, J = 7.4 Hz), 6.68 (1H, s), 4.33 (1H, q, J = 4.8 Hz), 3.82 (3H, s), 2.73 (2H, t, J = 7.4 Hz), 2.27-2.18 (1H, m), 2.07-2.01 (1H, m); 13C-NMR (CD3OD) δ: 173.82, 159.24, 132.56, 131.76, 129.42, 123.65 (q, JCF = 273.5 Hz), 119.90, 109.14, 55.92, 53.69, 31.64, 29.57 (q, JCF = 40.4 Hz), 27.44; 19F-NMR (CD3OD) δ: -66.38; ESI-MS m/z: 318 (M+H)+, ESI-HRMS: calcd. for C13H15F3N3O3 (M+H)+, 318.1060; found, m/z 318.1067; chiral HPLC tR = 13.2 min

(R)-2-amino-4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)butanoic acid ((R)-6)

The same treatment of (R)-4 (26.0 mg, 60 µmol) as described in above gave (R)-6 (16.8 mg, 90%) as yellow oil. The 1H-, 13C- NMR and IR of these samples were identical to these record for (S)-6

[α]D +15° (c 2.0, MeOH); chiral HPLC tR = 17.0 min

(S)-2-amino-4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)-4-oxobutanoic acid ((S)-7)
To a stirred solution of (S)-3 (31.6 mg, 72 µmol) in acetic acid (12 ml), concentrated HCl (12 ml) was added. The reaction mixture was stirred for 12 hours at 50°C, then concentrated. The residue was subjected to silica chromatography (CH<sub>2</sub>Cl<sub>2</sub> : MeOH : H<sub>2</sub>O : acetic acid = 10 : 2 : 0.25 : 0.05) to afford a colorless solid (22.3 mg, 94%).

[α]<sub>D</sub> -14° (c 2.0, MeOH); IR (film) cm<sup>-1</sup> : 2940, 1670, 1610; <sup>1</sup>H-NMR (CD<sub>3</sub>OD) δ: 7.87 (1H, d, J = 8.0 Hz), 6.95 (1H, d, J = 8.6 Hz), 6.81 (1H, s), 3.99-3.97 (4H, m), 3.72 (1H, d, J = 19.5 Hz), 3.55 (1H, d, J = 19.5 Hz); <sup>13</sup>C-NMR (CD<sub>3</sub>OD) δ: 199.11, 179.04, 160.88, 136.24, 132.52, 128.79, 123.34 (q, 1J<sub>CF</sub> = 273.9 Hz), 119.74, 111.08, 56.54, 51.84, 29.54 (q, 2J<sub>CF</sub> = 40.4 Hz), 123.2; <sup>19</sup>F-NMR (CD<sub>3</sub>OD) δ: -66.83; ESI-MS m/z: 332 (M+H)<sup>+</sup>, ESI-HRMS: calcd. for C<sub>13</sub>H<sub>13</sub>F<sub>3</sub>N<sub>3</sub>O<sub>4</sub> (M+H)<sup>+</sup>, 332.0853; found, m/z 332.0866; chiral HPLC t<sub>R</sub> = 10.2 min.

(R)-2-Amino-4-(2-methoxy-4-(3-(trifluoromethyl)-3H-diazirin-3-yl)phenyl)-4-oxobutanoic acid ((R)-7)

The same treatment of (R)-4 (31.8 mg, 72 µmol) as described in above gave (R)-7 (21.0 mg, 88%) as yellow oil. The <sup>1</sup>H-, <sup>13</sup>C- NMR and IR of these samples were identical to these record for (S)-6

[α]<sub>D</sub> +14° (c 2.0, MeOH); chiral HPLC t<sub>R</sub> = 15.0 min

Photolysis of the diazirinyl compounds in methanol

Methanolic solution of (S)-6 or 7 (0.5 mM) was placed in a quartz cuvette. After replacing the inner atmosphere with nitrogen, photolysis was carried out with 15 W black-light (UVP Inc., San Gabriel, California, USA) at a distance 2 cm from the surface of light source.

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References

Figure legends

Figure 1
Friedel-Crafts reactions with diazirinyl compound 1 and optically pure aspartic acid derivative 2.

Scheme 1
Synthesis of optically pure diazirinyl homophenylalanine derivatives.
Reagents and conditions: (a) Triethylsilane, trifluoroacetic acid, (S)- 76%, (R)- 80%; (b) NaOH, MeOH, (S)- 91%, (R)- 90%; (c) 6N HCl, acetic acid, 80 °C, (S)- 94%, (R)- 88%.

Figure 2
Chiral HPLC chromatogram of synthetic diazirinyl (S)- or (R)- 6 and (S)- or (R)- 7 with chiral HPLC.
Condition: CHIROBIOTIC T (Astec) 4.6 x 250 mm, eluted with 10% EtOH – H2O; flow rate 1.0 ml/min; UV detection at 210 nm.

Figure 3
Photolysis of the 0.5 mM of (S)- 6 (a) and (S)- 7 (b) in methanol with 15 W black light.
The photolysis reaction mixture, at the times (in min), was indicated with numbers.
Figure 1

![Chemical structure diagram]

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a no reaction occurred, b the starting material 1 was decomposed.
Scheme 1

1

2    F₃C -N
3    F₃C -N
4    F₃C -N
5    F₃C -N
6    F₃C -N
7    F₃C -N
8    F₃C -N
9    F₃C -N
10   F₃C -N
11   F₃C -N
12   F₃C -N
13   F₃C -N
14   F₃C -N
15   F₃C -N
16   F₃C -N

The reaction steps are:

a) Reaction 1
b) Reaction 2

The chemical structures are:

3: F₃C -N
4: F₃C -N
5: F₃C -N
6: F₃C -N
7: F₃C -N

The products are:

5: F₃C -N
6: F₃C -N
7: F₃C -N

The reactions involve the transformation of the starting material (3) to the final product (5) through intermediate (6).
Figure 2
Figure 3
(a) (b)