SYNTHETIC STUDIES ON PLAKINIDINES

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This paper is dedicated to Professor Tohru Fukuyama on the occasion of his 70th birthday.

Abstract – Synthetic studies on plakinidines are described. As a model study for the construction of the dihydropyridone ring at the final stage of the synthesis, we investigated a Meyer–Schuster rearrangement/aza-Michael cyclization cascade. The B,C,D,E ring system possessing a pyrrolo[2,3,4-kl]acridine structure was constructed via a benzyne-mediated cyclization/functionalization sequence that involved the formation of a β,β-diarylethylamine derivative and a palladium-catalyzed double aryl amination of a 3-aryldindoline intermediate as key processes.

INTRODUCTION

The plakinidine alkaloid family, including plakinidines A (1), B (2), C (3), and D (4) having a highly functionalized pyrrolo[2,3,4-kl]acridine skeleton1 (Figure 1), exhibit a potent cytotoxicity against HCT-116 murine leukemia cells.2b In addition, plakinidines A (1) and B (2) exhibit antiparasitic activity against Nippostrongylus brasiliensis.2a Due to their biological activities and their densely fused pentacyclic structure, which includes the fully substituted B ring, this family of compounds have attracted a great deal of attention as synthetic targets. To date, two synthetic studies on plakinidines have been reported. Kitahara3 described the synthesis of a pentacyclic core lacking the amino group at the 12-position of the B ring via formation of the acridine skeleton at the early stage of the synthesis and subsequent cyclization of a ketene intermediate that was thermally generated from a Meldrum’s acid derivative, affording the pyridone ring.5 Meanwhile, Fukuyama et al.4 successfully synthesized the fully functionalized pentacyclic core by a well-designed late stage aromatization strategy for the construction...
of the B ring, whereas they failed to set up the required oxidation state of the pyrroloacridine system at the final stage of the synthesis. In spite of these significant efforts toward the synthesis of plakinidines, a total synthesis has not been reported to date. Herein, we report the construction of the tetracyclic core of plakinidines by utilizing our previously reported benzyne-mediated cyclization-functionalization sequence and a model study for the construction of the pyridone ring through a Meyer–Schuster rearrangement/aza-Michael cyclization cascade.

Figure 1. Plakinidine alkaloids

RESULTS AND DISCUSSIONS
Our retrosynthetic analysis of plakinidines is shown in Scheme 1. There were two key issues to be addressed in the synthesis of plakinidines. One was the construction of the pyrroloacridine core at the appropriate synthetic stage; the formation of the fully conjugated acridine skeleton at an early stage of the synthesis can be disadvantageous because its poor solubility and reactivity could hinder the subsequent

Scheme 1. Retrosynthetic analysis of plakinidines
The other issue was the construction of the hexasubstituted B ring bearing the amino group and the fused pyridone ring. To circumvent the solubility issue, we selected tetrahydro derivative 5 as a precursor, which would afford the desired plakinidines upon oxidation at the final stage of the synthesis. For the crucial construction of the pyridone ring at the hindered position, we planned a cascade reaction starting with a Meyer–Schuster rearrangement and a subsequent aza-Michael addition from the ortho-aminophenyl propargylic alcohol derivative 7. The tetrahydropyrroloacridine framework 8 would be easily assembled from β,β-diarylethylamine derivative 11 by performing a benzyne-mediated cyclization-functionalization strategy previously developed in our group, followed by a double aryl amination reaction of the as-generated indoline 9 according to Nozaki’s protocol.

At the outset of the research, we examined the Meyer–Schuster rearrangement/aza-Michael addition cascade using 3-(2-aminophenyl)propyn-1-ol 10 as a model substrate (Table 1). First, 10 was heated with Brønsted acids such as hydrochloric acid and p-TsOH, following the seminal work reported by Pisaneschi and Politanskaya (entries 1 and 2). The desired pyridone derivative 14 was obtained, albeit in a low yield. We then examined various Lewis acids to find milder conditions. Thus, π-philic Lewis acids such as PtCl or AuCl were inefficient (entries 3 and 4). On the other hand, the reaction of 10 with Bi(OTf) or Sc(OTf) provided pyridone 14 in moderate yields (entries 5 and 6). Eventually, we found that SnCl provided the most effective conditions, affording pyridone 14 in 66% yield (entry 7).

**Table 1.** Model study of Meyer–Schuster rearrangement/aza-Michael addition cascade

<table>
<thead>
<tr>
<th>entry</th>
<th>condition</th>
<th>yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>conc. HCl, H2O, reflux</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>p-TsOH, EtOH, reflux</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>PtCl, t-BuOH, 60 °C</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>AuCl, AgSbF, MeOH/H2O, 60 °C</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Bi(OTf), EtOH/1,2-DCE, 70 °C</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>Sc(OTf), CH2Cl2/EtOH, 60 °C</td>
<td>44</td>
</tr>
<tr>
<td>7</td>
<td>SnCl, t-BuOH/H2O, reflux</td>
<td>66</td>
</tr>
</tbody>
</table>

Having established the optimal conditions for the Meyer–Schuster rearrangement/aza-Michael addition cascade, we next initiated the synthetic studies on the key tetrahydropyrroloacridine intermediate. The
preparation of β,β-diarylethylamine derivative 20 commenced with the conjugate addition of the lithiated 2,6-dibromiodobenzene derivative 15\textsuperscript{11} to nitroalkene 17\textsuperscript{12} (Scheme 2), in which the selective lithium–iodine exchange\textsuperscript{11a,13} at 15 was promoted by treatment with n-BuLi (1 eq.) in toluene at −78 °C. Upon addition of nitroalkene 17, the desired conjugate addition proceeded smoothly to give nitroalkane 18. Reduction of the nitro group of 18 using a combination of Fe/FeCl\textsubscript{2}\textsuperscript{11a} and the subsequent protection of the resultant primary amine 19 as the corresponding Boc carbamate gave 20.

Scheme 2. Preparation of β,β-diarylethylamine derivative 20

With β,β-diarylethylamine derivative 20 in hand, we conducted the key benzyne-mediated cyclization/functionalization sequence\textsuperscript{6} (Scheme 3). Upon treatment of 20 with Mg(TMP)\textsubscript{2}·2LiCl (TMP: 2,2,6,6-tetramethylpiperidyl) at −78 °C, followed by rising the reaction temperature to 0 °C, the intramolecular cyclization of the amide anion with the generated benzyne provided 7-magnesioindoline 22, which was then trapped by tosyl azide to furnish 7-azidoindoline 23 in excellent yield. Reduction of the azide by Staudinger’s condition and subsequent protection of the resulting primary amine as the corresponding methyl carbamate afforded 24. Finally, the desired compound 26 was obtained by conversion of the MOM ether to triflate.

Our attention was then turned to the construction of the C and D rings (Scheme 4). The planned double amination reaction of bromo triflate 26 using Nozaki’s protocol\textsuperscript{9a} proceeded nicely to give tetracyclic compound 27 in good yield. After removal of the benzyl group, the nitro group was introduced by using a combination of n-Bu\textsubscript{4}NNO\textsubscript{3} and Tf\textsubscript{2}O\textsuperscript{14} to provide 29. Reduction of the nitro group, followed by treatment of the resulting phenol with Tf\textsubscript{2}O afforded triflate 30. For the introduction of the propargyl alcohol unit, we examined Sonogashira coupling reaction; however, all attempts including other coupling reactions
were unsuccessful.\textsuperscript{15} These disappointing results could be attributed to the steric hindrance around the reaction site or to the electron-donating properties exerted by the four nitrogen atoms on the B ring.

In conclusion, we have established a novel synthetic approach to construct the tetracyclic core of plakinidine. The most salient feature of our synthesis includes the efficient introduction of three nitrogen atoms in the highly fused core skeleton of plakinidine through two cyclization processes, i.e., a benzyne-mediated cyclization/functionalization sequence and a palladium-catalyzed double amination reaction. Further investigation toward the total synthesis of plakinidine alkaloids is currently ongoing in our laboratory.
EXPERIMENTAL

Materials were obtained from commercial suppliers and used without further purification unless otherwise mentioned. Anhydrous THF and CH$_2$Cl$_2$ were purchased from Kanto Chemical Co. Inc. Anhydrous toluene, Et$_3$N, pyridine, xylene, and DMF were dried and distilled according to the standard protocols. 2,2,6,6-Tetramethylpiperidine was distilled from CaH$_2$ and stored over KOH. Flash column chromatography was performed on Silica Gel 60N (Kanto, spherical neutral, 40–50 μm) using the indicated eluent. Preparative TLC and analytical TLC were performed on Merck 60 F$_{254}$ glass plates pre-coated with a 0.25 mm thickness of silica gel. IR spectra were measured on a SHIMADZU FTIR–8300 spectrometer. NMR spectra were recorded on a JNM-AL400 spectrometer with tetramethylsilane (0 ppm) and chloroform (7.26 ppm) as internal standards. Chemical shifts were expressed in δ (ppm) values, and coupling constants were expressed in hertz (Hz). The following abbreviations are used for spin multiplicity: s = singlet, d = doublet, t = triplet, m = multiplet, and br = broad. Mass spectra were recorded on a JMS-700 (EI) or a Brucker micrOTOF II (ESI).

2,3-Dihydroquinolin-4(1H)-one (14)

A sealed tube equipped with a magnetic stirring bar and a screw cap was charged with aniline 12$^{10}$ (10.6 mg, 72.0 μmol), SnCl$_2$ (12.7 mg, 67.0 μmol), t-BuOH (340 μL), and H$_2$O (340 μL). The reaction mixture was stirred and heated at reflux for 1 h. The reaction was quenched with 1 M aqueous NaOH and aqueous layer was extracted with CH$_2$Cl$_2$. The combined organic extracts were washed with brine, dried over anhydrous Na$_2$SO$_4$, filtered, and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel (hexanes-EtOAc = 1:1) to afford quinolinone 14 (7.0 mg, 48 μmol, 66%) as an orange solid. Spectroscopic data were identical with those previously reported.$^{16}$

5-(Benzyloxy)-1,3-dibromo-2-(1-(2-(methoxymethoxy)phenyl)-2-nitroethyl)benzene (18)

A flame-dried 200-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with aryl iodide 15$^{11}$ (4.16 g, 8.89 mmol) and toluene (45.0 mL). The mixture was cooled in a dry ice-acetone bath, and to the solution was added n-BuLi (1.55 M in hexanes, 5.80 mL, 8.99 mmol) dropwise over 5 min. After stirring for 10 min, a solution of nitro-olefin 17$^{12}$ (1.86 g, 8.89 mmol) in toluene (20.0 mL) was added dropwise to the suspension at –78 °C over 5 min. After stirring for 10 min, the reaction was quenched with sat. aqueous ammonium chloride, and then the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous Na$_2$SO$_4$, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 7:1) to afford nitro alkane 18 (4.19 g, 7.60 mmol, 86%) as a colorless oil. R$_f$ = 0.30 (hexanes-CH$_2$Cl$_2$ = 3:1); IR (neat, cm$^{-1}$): 1591, 1556, 1456, 1375, 315.
1238, 1001; ¹H NMR (400 MHz, CDCl₃): δ 7.42–7.36 (m, 5H), 7.31–7.17 (m, 3H), 7.13–7.05 (m, 2H), 6.93 (ddd, 1H, J = 7.6, 6.8, 1.6 Hz), 6.04 (dd, 1H, J = 7.6, 6.8 Hz), 5.40 (dd, 1H, J = 13.6, 7.6 Hz), 5.15 (d, 1H, J = 7.6 Hz), 5.09 (dd, 1H, J = 13.6, 6.8 Hz), 5.07 (d, 1H, J = 7.6 Hz), 5.02 (s, 2H), 3.27 (s, 3H);

¹³C NMR (100 MHz, CDCl₃): δ 158.0, 154.7, 135.6, 129.7, 129.0, 128.7, 128.9, 128.5, 127.6, 125.5, 120.9, 113.6, 93.5, 70.5, 60.4, 56.0, 44.1, 21.0, 14.2; HRMS (EI) m/z: calcd. for C₂₃H₂₁⁷⁹Br₂NO₅ [M⁺] 548.9786, found 548.9777.

**tert-Butyl (2-(4-(benzyloxy)-2,6-dibromophenyl)-2-(2-(methoxymethoxy)phenyl)ethyl)-carbamate (20)**

A 500-mL, round-bottomed flask equipped with a reflux condenser and a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with 18 (4.19 g, 7.60 mmol), Fe (4.24 g, 75.9 mmol), FeCl₂·4H₂O (963 mg, 7.60 mmol), saturated aqueous ammonium chloride (14.0 mL), EtOAc (14.0 mL), and EtOH (42.0 mL). The reaction mixture was stirred and heated at reflux for 2 h. The resulting solid was removed by filtration through a pad of Celite®, and the filter cake was washed thoroughly with MeOH. Then, the filtrate was concentrated under reduced pressure. The residue was basified with 4 M NaOH to pH = 14 and filtered through a pad of Celite®, and the filter cake was washed thoroughly with MeOH. Then, the filtrate was concentrated under reduced pressure to give a crude amine, which was used to the next reaction without further purification.

To the residue was added sat. aqueous NaHCO₃ (35.0 mL), THF (70.0 mL), and Boc₂O (2.49 g, 11.4 mmol). The reaction mixture was stirred at room temperature for 11 h. The reaction mixture was diluted with EtOAc, and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous Na₂SO₄, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 6:1) to afford the carbamate 20 (3.35 g, 5.39 mmol, 71% over 2 steps from 18) as a white powder. R₉ = 0.19 (hexanes-EtOAc = 5:1); IR (neat, cm⁻¹): 1684, 1592, 1237, 1163, 1011, 754; ¹H NMR (400 MHz, CDCl₃): δ 7.50–6.92 (m, 11H), 5.13 (dd, 1H, J = 8.4, 7.2 Hz), 5.02–4.97 (m, 3H), 4.92 (d, 1H, J = 6.8 Hz), 4.60 (brs, 1H), 4.20–3.96 (m, 2H), 3.09 (s, 3H), 1.40 (s, 9H); ¹³C NMR (100 MHz, CDCl₃): δ 157.2, 155.7, 155.0, 135.8, 131.8, 130.0, 128.7, 128.3, 128.2, 127.7, 127.5, 120.4, 113.0, 93.3, 79.1, 70.4, 55.6, 45.75, 45.70, 40.8, 28.4, 14.2; HRMS (ESI) m/z: calcd. for C₂₈H₃₁⁷⁹Br₂NNaO₅ [M+Na⁺] 642.0461, found 642.0441.

**Preparation of Mg(TMP)₂·2LiCl.⁶**

A 300-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with Mg turnings (703 mg, 28.9 mmol). The flask was evacuated under
heating for 30 min and then backfilled with argon. After addition of dry THF (72.0 mL), 1,2-dichloroethane (2.27 mL, 28.9 mmol) was added dropwise to the flask at room temperature. The reaction mixture was stirred for approximately an hour until all magnesium was consumed. Another flame-dried 500-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with 2,2,6,6-tetramethylpiperidine (9.80 mL, 58.0 mmol) and dry THF (35.0 mL). The solution was cooled in dry ice-acetone bath, and to the solution was added \( n \)-BuLi (1.55 M in \( n \)-hexane, 37.0 mL, 57.8 mmol) dropwise at \(-78^\circ C\). The resulting suspension was allowed to warm to 0 °C and stirred at the same temperature for 30 min. To the resulting pale yellow solution was transferred the \( \text{MgCl}_2 \)-THF solution via cannula, and the mixture was stirred for another an hour to afford a pale yellow solution of \( \text{Mg(TMP)}_2 \cdot 2\text{LiCl} \) (0.180 M in \( n \)-hexane-THF). The reagent was titrated prior to use at 0 °C against benzoic acid using 4-(phenylazo)diphenylamine as indicator.

**tert-Butyl 7-azido-6-(benzyloxy)-4-bromo-3-(2-(methoxymethoxy)phenyl)indoline-1-carboxylate (23)**

A flame-dried 500-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with the carbamate 20 (3.35 g, 5.39 mmol), and THF (20.0 mL). The mixture was cooled in a dry ice-acetone bath, and to the solution was added \( \text{Mg(TMP)}_2 \cdot 2\text{LiCl} \) (0.180 M in THF, 150 mL, 27.0 mmol) at \(-78^\circ C\) dropwise over 5 min. The reaction mixture was allowed to warm to 0 °C and stirred for 1 h. Then, \( \text{TsN}_3 \) (8.20 mL, 53.6 mmol) was added to the reaction mixture at \(-78^\circ C\), and the resulting mixture was allowed to warm to 0 °C and stirred for 1 h. The reaction was quenched with sat. aqueous ammonium chloride, and the resulting mixture was allowed to warm to 0 °C and stirred for 1 h. The reaction was quenched with sat. aqueous ammonium chloride, and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous \( \text{Na}_2\text{SO}_4 \), filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-CH\(_2\)Cl\(_2\) = 1:1 to hexanes-EtOAc = 5:1) to afford azide 23 (2.80 g, 4.82 mmol, 89%) as a pale yellow oil. \( R_f = 0.27 \) (hexanes-EtOAc = 5:1); IR (neat, cm\(^{-1}\)): 2120, 1712, 1336, 1154, 1001, 754; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \( \delta \) 7.52–7.15 (m, 6H), 7.10 (d, \( J = 8.4 \) Hz), 6.86–6.82 (m, 2H), 6.67 (d, 1H, \( J = 7.2 \) Hz), 5.26 (d, 1H, \( J = 6.4 \) Hz), 5.21 (d, 1H, \( J = 6.4 \) Hz), 5.12 (s, 2H), 4.54 (dd, 1H, \( J = 8.0, 2.0 \) Hz), 4.21 (dd, 1H, \( J = 11.2, 8.0 \) Hz), 4.08 (dd, 1H, \( J = 11.2, 2.0 \) Hz), 3.44 (s, 3H), 1.39 (s, 9H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \( \delta \) 154.1, 153.7, 153.1, 138.3, 135.7, 130.8, 129.6, 128.7, 128.3, 128.2, 128.0, 127.5, 121.7, 119.3, 114.6, 113.8, 112.9, 94.1, 81.4, 71.9, 59.2, 56.0, 42.3, 28.0; HRMS (EI) \( m/z \): calcd. for \( \text{C}_{28}\text{H}_{29}^{79}\text{BrN}_4\text{O}_5 \) [\( \text{M}^+ \)] 580.1321, found 580.1306.

**tert-Butyl 7-amino-6-(benzyloxy)-4-bromo-3-(2-(methoxymethoxy)phenyl)indoline-1-carboxylate**
A 50-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with azide 23 (2.30 g, 3.96 mmol), and THF (10.0 mL). To the mixture was added tri-n-butylphosphine (1.48 mL, 5.94 mmol) dropwise at 0 °C. Nitrogen gas started to evolve within 5 min. The reaction mixture was allowed to warm to room temperature and stirred for 30 min. To the iminophosphorane generated in situ was added H2O (5.00 mL), and the reaction mixture was stirred at room temperature for 15 h. The reaction mixture was diluted with EtOAc and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous Na2SO4, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 6:1) to afford the aniline (1.49 g, 2.68 mmol, 68%) as a white powder. Rf = 0.27 (hexanes-EtOAc = 5:1); IR (neat, cm−1): 1685, 1489, 1370, 1155, 1003, 753; 1H NMR (400 MHz, CDCl3): δ 7.50–7.32 (m, 5H), 7.18 (ddd, 1H, J = 8.4, 6.8, 1.6 Hz), 7.11 (d, 1H, J = 8.4 Hz), 6.85 (dd, 1H, J = 7.6, 6.8 Hz), 6.78 (s, 1H), 6.75 (d, 1H, J = 7.6 Hz), 5.28 (d, 1H, J = 6.8 Hz), 5.21 (d, 1H, J = 6.8 Hz), 5.08 (d, 1H, J = 11.2 Hz), 5.04 (d, 1H, J = 11.2 Hz), 4.90 (brs, 2H), 4.55 (dd, 1H, J = 8.4, 2.0 Hz), 4.21 (dd, 1H, J = 11.2, 8.4 Hz), 4.04 (dd, 1H, J = 11.2, 2.0 Hz), 3.46 (s, 3H), 1.37 (s, 9H); 13C NMR (100 MHz, CDCl3): δ 154.1, 153.8, 148.1, 136.6, 130.9, 130.6, 129.2, 128.6, 128.21, 128.16, 127.9, 127.6, 126.9, 121.7, 113.7, 111.7, 105.8, 94.2, 81.3, 71.3, 58.5, 56.0, 41.6, 28.1; HRMS (ESI) m/z: calcd. for C28H32Br2N2O5 [M+H+] 555.1489, found 555.1463.

tert-Butyl 6-(benzyloxy)-4-bromo-3-(2-hydroxyphenyl)-7-((methoxycarbonyl)amino)-indoline-1-carboxylate (25)

A 30-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with the aniline (1.49 g, 2.68 mmol), and CH2Cl2 (13.0 mL). The mixture was cooled in ice-water bath, and to the solution was added pyridine (325 μL, 4.02 mmol) and methyl chloroformate (249 μL, 3.22 mmol). The reaction mixture was allowed to warm to room temperature and stirred for 10 min. The reaction was quenched with 1 M aqueous HCl and aqueous layer was extracted with CH2Cl2. The combined organic extracts were washed with brine, dried over anhydrous Na2SO4, filtered, and concentrated under reduced pressure to give a crude carbamate, which was used to the next reaction without further purification.

A 100-mL, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with the crude carbamate, i-PrOH (65.0 mL), and THF (65.0 mL). To the mixture was added conc. HCl (16.8 mL, 201 mmol) at room temperature and the reaction mixture was stirred at room temperature for 40 h. The reaction mixture was diluted with EtOAc and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous Na2SO4, filtered, and concentrated under reduced pressure. The residue was purified by column
chromatography on silica gel (hexanes-EtOAc = 4:1 to 2:1) to afford the phenol 25 (499 mg, 877 \( \mu \)mol, 33% over 2 steps from aniline) as a pink powder. \( R_f = 0.16 \) (hexanes-EtOAc = 3:1); IR (neat, cm\(^{-1}\)): 1699, 1684, 1507, 1457; \(^1\)H NMR (400 MHz, CDCl\(_3\)):\( \delta \) 7.74 (brs, 1H), 7.44–7.33 (m, 5H), 7.10 (ddd, 1H, \( J = 8.0, 8.0, 1.2 \) Hz), 6.90 (s, 1H), 6.80 (dd, 1H, \( J = 8.0, 6.8 \) Hz), 6.76 (d, 1H, \( J = 8.0 \) Hz), 6.71 (d, 1H, \( J = 6.8 \) Hz), 5.10 (s, 2H), 4.97 (brs, 1H), 4.54 (dd, 1H, \( J = 8.8, 2.4 \) Hz), 4.30 (dd, 1H, \( J = 11.6, 8.8 \) Hz), 4.09 (dd, 1H, \( J = 11.6, 2.4 \) Hz), 3.69 (s, 3H), 1.40 (s, 9H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)):\( \delta \) 154.8, 154.5, 154.2, 153.4, 139.6, 136.5, 129.2, 128.4, 128.1, 127.9, 127.6, 127.2, 120.2, 116.5, 115.7, 115.2, 113.2, 82.1, 71.3, 71.2, 58.6, 52.6, 41.6, 28.0; HRMS (ESI) \( m/z \): calcd. for C\(_{28}\)H\(_{29}\)BrN\(_2\)O\(_6\) [M+Na\(^+\)] 591.1101, found 591.1074.

**tert-Butyl 6-(benzzyloxy)-4-bromo-7-((methoxycarbonyl)amino)-3-(2-(((trifluoromethyl)sulfonyl)oxy)phenyl)indoline-1-carboxylate (26)**

A 20-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with the phenol 25 (499 mg, 877 \( \mu \)mol), and CH\(_2\)Cl\(_2\) (9.00 mL). The mixture was cooled in ice-water bath, and to the solution was added Et\(_3\)N (184 \( \mu \)L, 1.32 mmol) and Tf\(_2\)O (148 \( \mu \)L, 880 \( \mu \)mol). The solution was then stirred at same temperature for 5 min. The reaction was quenched with sat. aqueous ammonium chloride and the aqueous layer was extracted with CH\(_2\)Cl\(_2\). The combined organic extracts were washed with brine, dried over anhydrous Na\(_2\)SO\(_4\), filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 6:1) to afford the triflate 26 (551 mg, 785 \( \mu \)mol, 90%) as a white foam. \( R_f = 0.35 \) (hexanes-EtOAc = 3:1); IR (neat, cm\(^{-1}\)): 1734, 1698, 1506, 1418, 1218, 1141; \(^1\)H NMR (400 MHz, CDCl\(_3\)):\( \delta \) 7.67 (brs, 1H), 7.45 (d, 2H, \( J = 7.6 \) Hz), 7.37 (dd, 2H, \( J = 7.6, 7.6 \) Hz), 7.36–7.20 (m, 4H), 6.90 (s, 1H), 6.83 (d, 1H, \( J = 7.6 \) Hz), 5.10 (s, 2H), 4.60 (dd, 1H, \( J = 8.8, 2.4 \) Hz), 4.36 (dd, 1H, \( J = 11.6, 8.8 \) Hz), 4.06 (dd, 1H, \( J = 11.6, 2.4 \) Hz), 3.69 (s, 3H), 1.41 (s, 9H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)):\( \delta \) 155.1, 154.1, 153.7, 146.7, 139.2, 136.3, 134.5, 128.9, 128.8, 128.4, 127.9, 127.2, 123.3, 121.4, 120.1, 116.9, 116.4, 116.0, 113.3, 82.5, 71.3, 58.2, 52.3, 40.8, 27.9; HRMS (ESI) \( m/z \): calcd. for C\(_{28}\)H\(_{29}\)BrF\(_3\)N\(_2\)NaO\(_8\)S [M+Na\(^+\)] 723.0594, found 723.0568.

**Di-tert-butyl 4-(benzzyloxy)-3-((methoxycarbonyl)amino)-1,10b-dihydropyrrolo-[2,3,4-k]acridine-2,6-dicarboxylate (27)**

A 20-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with Pd\(_2\)(dba)\(_3\)·CHCl\(_3\) (163 mg, 157 \( \mu \)mol), Xantphos (182 mg, 314 \( \mu \)mol), and xylene (2.60 mL). Triflate 26 (551 mg, 785 \( \mu \)mol), BocNH\(_2\) (139 mg, 1.18 mmol), and K\(_3\)PO\(_4\) (500 mg, 2.36 mmol) were added to the reaction mixture. The reaction mixture was stirred and heated at 100
°C for 5 h. The reaction was quenched with sat. aqueous ammonium chloride and the aqueous layer was extracted with EtOAc. The combined organic extracts were washed with brine, dried over anhydrous Na₂SO₄, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 3:1) to afford the dihydroacridine 27 (320 mg, 545 µmol, 69%) as a red foam. Rf = 0.28 (hexanes-EtOAc = 3:1); IR (neat, cm⁻¹): 1714, 1349, 1153, 732; ¹H NMR (400 MHz, CDCl₃): δ 7.84–7.60 (m, 3H), 7.50–7.22 (m, 4H), 7.17 (dd, 1H, J = 8.0, 6.4 Hz), 7.07 (s, 1H), 7.03 (d, 1H, J = 8.0 Hz), 5.11 (s, 2H), 4.87 (dd, 1H, J = 9.6, 9.6 Hz), 4.44 (dd, 1H, J = 9.6, 9.6 Hz), 4.03 (dd, 1H, J = 9.6, 9.6 Hz), 3.66 (s, 3H), 1.58 (s, 9H), 1.53 (s, 9H); ¹³C NMR (100 MHz, CDCl₃): δ 170.7, 154.3, 153.7, 153.0, 152.1, 138.3, 136.9, 134.5, 133.0, 132.7, 128.7, 128.2, 128.1, 127.5, 126.9, 126.1, 125.3, 125.2, 125.0, 121.4, 114.2, 105.9, 82.0, 81.8, 71.4, 60.0, 57.0, 52.0, 36.4, 28.0, 27.8, 20.7, 13.9 (a mixture of two rotamer); HRMS (ESI) m/z: calcd. for C₃₃H₃₈N₃O₇ [M+H⁺] 588.2704, found 588.2682.

**Di-tert-butyl 4-hydroxy-3-((methoxycarbonyl)amino)-1,10b-dihydropyrrolo[2,3,4-kl]-acridine-2,6-dicarboxylate (28)**

A 50-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with benzyl ether 27 (311 mg, 530 mmol), 10% palladium on activated carbon (56.4 mg, 53.0 µmol), EtOAc (2.50 mL), and EtOH (2.50 mL). The mixture was stirred under a hydrogen atmosphere (1 atm) at room temperature for 10 h. The reaction mixture was filtered through a pad of Celite®, and the filter cake was washed thoroughly with EtOAc. Then, the filtrate was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 7:1) to afford the phenol 28 (216 mg, 434 µmol, 82%) as a pale yellow oil. Rf = 0.39 (hexanes-EtOAc = 3:1); IR (neat, cm⁻¹): 3155, 1714, 1351, 1155, 733; ¹H NMR (400 MHz, CDCl₃): δ 9.96 (brs, 1H), 8.28 (brs, 1H), 7.74 (dd, 1H, J = 8.4, 1.2 Hz), 7.31–7.24 (m, 1H), 7.16 (ddd, 1H, J = 7.6, 7.2, 1.2 Hz), 7.09 (s, 1H), 7.01 (d, 1H, J = 7.6 Hz), 4.90 (dd, 1H, J = 10.0, 9.2 Hz), 4.40 (dd, 1H, J = 10.0, 8.8 Hz), 3.97 (dd, 1H, J = 9.2, 8.8 Hz), 3.79 (s, 3H), 1.60 (s, 9H), 1.57 (s, 9H); ¹³C NMR (100 MHz, CDCl₃): δ 171.1, 156.5, 152.2, 149.8, 138.5, 133.5, 132.6, 132.3, 126.5, 125.4, 121.5, 114.3, 112.8, 82.9, 82.4, 60.3, 57.7, 53.2, 36.6, 28.2, 21.0, 14.1; HRMS (ESI) m/z: calcd. for C₂₆H₂¹₃N₃NaO₇ [M+Na⁺] 520.2054, found 520.2043.

**Di-tert-butyl 4-hydroxy-3-((methoxycarbonyl)amino)-5-nitro-1,10b-dihydropyrrolo-[2,3,4-kl]acridine-2,6-dicarboxylate (29)**

A 20-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was charged with Tf₂O (73.0 µL, 434 µmol), n-Bu₄NNO₃ (132 mg, 434 µmol), and CH₂Cl₂ (2.00 mL). The mixture was cooled in dry ice-acetone bath, and to the reaction mixture was
added phenol 28 (216 mg, 434 µmol) in CH₂Cl₂ (2.50 mL). The reaction mixture was stirred for at same
temperature for 10 min. The reaction was quenched with sat. aqueous NaHCO₃ and the aqueous layer was
extracted with CH₂Cl₂. The combined organic extracts were washed with brine, dried over anhydrous
Na₂SO₄, filtered, and concentrated under reduced pressure. The residue was purified by column
chromatography on silica gel (hexanes-EtOAc = 3:1) to afford the nitrophenol 29 (59.0 mg, 109 µmol,
25%) as a red oil. R₇ = 0.1 (hexanes-EtOAc = 3:1); IR (neat, cm⁻¹): 2979, 1723, 1540, 1349, 1152, 732;
¹H NMR (400 MHz, CDCl₃): δ 10.9 (s, 1H), 8.27 (brs, 1H), 7.87 (d, 1H, J = 7.2 Hz), 7.36 (dd, 1H, J = 8.4,
7.2 Hz), 7.33–7.20 (m, 1H), 7.08 (d, 1H, J = 8.0 Hz), 4.87 (dd, 1H, J = 10.8, 9.6 Hz), 4.46 (dd, 1H, J =
10.0, 9.6 Hz), 4.11 (dd, 1H, J = 10.8, 10.0 Hz), 3.74 (s, 3H), 1.60 (s, 9H), 1.45 (s, 9H); ¹³C NMR (100
MHz, CDCl₃): δ 154.8, 152.7, 151.3, 151.1, 138.4, 138.1, 132.7, 128.3, 127.1, 126.3, 126.2, 124.6, 122.9,
113.6, 83.7, 83.6, 56.6, 52.9, 37.4, 28.1, 27.8, 14.1; HRMS (ESI) m/z: calcd. for C₂₆H₃₃N₄O₉ [M+Na⁺]
565.1905, found 565.1901.

**Di-tert-butyl 5-amino-4-hydroxy-3-((methoxycarbonyl)amino)-1,10b-dihydropyrrolo-
[2,3,4-kl]acridine-2,6-dicarboxylate**

A 10-mL, Schlenk tube equipped with a magnetic stirring bar, argon gas inlet, and a rubber septum was
charged with nitrophenol 29 (55.7 mg, 103 µmol), 10% palladium on activated carbon (11.0 mg, 10.3
µmol), EtOAc (500 µL), and EtOH (500 µL). The mixture was stirred under a hydrogen atmosphere (1
atm) at room temperature for 2 h. The reaction mixture was filtered through a pad of Celite®, and the
filter cake was washed thoroughly with EtOAc. Then, the filtrate was concentrated under reduced
pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 3:1) to
afford aminophenol (43.6 mg, 85.1 µmol, 83%) as a pale yellow solid. R₇ = 0.31 (hexanes-EtOAc = 3:1);
IR (neat, cm⁻¹): 2979, 1697, 1471, 1370, 1258, 1161, 732; ¹H NMR (400 MHz, CDCl₃): δ 10.1 (brs, 1H),
8.45 (brs, 1H), 7.56 (d, 1H, J = 8.4 Hz), 7.23 (dd, 1H, J = 8.4, 7.6 Hz), 7.17 (dd, 1H, J = 7.6, 7.6 Hz),
7.02 (d, 1H, J = 7.6 Hz), 4.85 (dd, 1H, J = 9.2, 9.2 Hz), 4.46 (dd, 1H, J = 9.2, 9.2 Hz), 3.89 (dd, 1H, J =
9.2, 9.2 Hz), 3.78 (s, 3H), 1.59 (s, 3H), 1.52 (s, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 156.5, 154.6, 152.6,
139.3, 137.3, 134.3, 131.4, 126.7, 126.2, 125.8, 124.9, 123.6, 122.5, 121.1, 115.6, 82.6, 82.3, 56.8, 53.2,
37.6, 28.3, 28.2; HRMS (ESI) m/z: calcd. for C₂₆H₃₃N₄O₇ [M+H⁺] 513.2344, found 513.2377.

**Di-tert-butyl 5-amino-3-((methoxycarbonyl)amino)-4-(((trifluoromethyl)sulfonyl)oxy)-
1,10b-dihydropyrrolo[2,3,4-kl]acridine-2,6-dicarboxylate (30)**

A 30-mL, two-necked, round-bottomed flask equipped with a magnetic stirring bar, argon gas inlet, and a
rubber septum was charged with aminophenol (43.0 mg, 83.9 µmol), and CH₂Cl₂ (800 µL). The mixture
was cooled in a dry ice-acetone bath, to the solution was added Et₃N (14.0 µL, 100 µmol) and Tf₂O (14.0
µL, 84.0 µmol). The solution was then stirred at same temperature for 15 min. The reaction was quenched with sat. aqueous ammonium chloride and the aqueous layer was extracted with CH₂Cl₂. The combined organic extracts were washed with 1 M aqueous HCl and brine, dried over anhydrous Na₂SO₄, filtered, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (hexanes-EtOAc = 3:1) to afford triflate 30 (50.8 mg, 78.8 µmol, 93%) as a white powder. R_f = 0.17 (hexanes-EtOAc = 3:1); IR (neat, cm⁻¹): 3166, 2980, 1691, 1356, 1146, 912, 733; ¹H NMR (400 MHz, CDCl₃): δ 10.1 (brs, 1H), 7.54–7.42 (m, 1H), 7.34–7.19 (m, 2H), 7.05 (d, 1H, J = 8.0 Hz), 4.88 (dd, 1H, J = 9.8, 8.8 Hz), 4.49 (dd, 1H, J = 9.8, 9.6 Hz), 4.00 (dd, 1H, J = 9.6, 8.8 Hz), 3.80 (s, 3H), 1.60 (s, 9H), 1.52 (s, 9H); ¹³C NMR (100 MHz, CDCl₃): δ 156.3, 154.2, 152.9, 148.2, 138.3, 133.2, 132.3, 130.8, 126.7, 126.4, 126.3, 125.0, 123.3, 121.4, 117.0, 116.3, 84.0, 83.5, 57.3, 53.5, 37.3, 28.2, 28.0; HRMS (ESI) m/z: calcd. for C₂₇H₃₁N₄NaO₉S [M+Na⁺] 667.1656, found 667.1624.

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REFERENCES AND NOTES


15. We also examined carbonylative coupling reaction to introduce vinyl ketone moiety. However, the desired compound was not obtained at all.

![Chemical structure](image)