Biogenetically inspired synthesis and skeletal diversification of indole alkaloids
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Table of contents

S2: General Methods & Materials.
S3-S21: Synthetic Procedures.
  S3-S4 : Development of Cu(I)-catalyzed cyclization to form dihydropyridine ring.
  S10-S15 : Synthesis of aspidosperma-type scaffold 25 and (±)-vincadifformine 32.
  S16-S18 : Synthesis of andranginine-type scaffold 27 and (±)-andranginine 7.
  S24 : Synthesis of unnatural tetracyclic scaffold 29.
S25-S69: The ¹H, ¹³C NMR spectra of synthetic compounds.
S70-S72: The COSY, HMBC, NOESY analysis of compound 29.
S73-S75: X-ray crystallographic data.
General Methods.

All reactions were performed under a nitrogen atmosphere unless otherwise specified. Microwave reactions were performed using a Biotage Initiator. NMR spectra were recorded on JEOL JNM-ECX 400 (\(^{1}H/400\) MHz, \(^{13}C/100\) MHz) spectrometer, JEOL JNM-ECX 600 (\(^{1}H/600\) MHz, \(^{13}C/150\) MHz) spectrometer and Bruker VSP 500 (\(^{1}H/500\) MHz, \(^{13}C/125\) MHz) spectrometer. Chemical Shifts are reported in \(\delta\) (ppm) using chloroform, acetonitrile as an internal standard of \(\delta\) 7.26, 1.94, and 77.16, 118.26 for \(^{1}H\) and \(^{13}C\)-NMR, respectively. Data for \(^{1}H\) NMR are reported as follows: chemical shift (multiplicity, coupling constant, number of hydrogens). Multiplicity is abbreviated as follows: s (singlet), d (doublet), t (triplet), q (quartet), quin ( quintet), m (multiplet), br (broad). ESI-Mass spectra were recorded on JEOL The AccuTOF LC-Plus JMS-T100. Optical rotations were recorded on JASCO DIP-360 digital polarimeter. The medium pressure liquid chromatography (MPLC) purifications were performed on a YAMAZEN YFLC-AI-580. Where necessary, solvents were distilled from appropriate drying agents prior to use. Reactions were monitored by thin layer chromatography using Merck Millipore TLC Silica gel F\(_{254}\) plates (0.25 mm) which were visualized using UV light, \(p\)-anisaldehyde stain and PMS stain. Flash column chromatography was performed using Kanto Silica Gel 60N.

Materials.

Commercial solvents and reagents were used as received with the following exceptions. The cationic Cu(I) complex, \([Cu(dppf)(MeCN)]PF_{6}\), was prepared with modified protocol reported by Kim and co-workers\(^{1}\) and purified by precipitation from CH\(_{2}\)Cl\(_{2}\)/Et\(_{2}\)O=1/1 solution as a yellow powder. The photo-redox catalyst \([Ru(bpy)_{3}]Cl_{2}\) was prepared from commercially available \([Ru(bpy)_{3}]Cl_{2}\) by an anion exchange with AgBF\(_{4}\) and recrystallization from water. \((S)\)-4-isopropyl-3-propioloyloxazolidin-2-one \(^{12}c,^{2}\) 2-(trimethylsilyl)ethyl-1H-imidazole-1-carboxylate (Teoc-Im),\(^{3}\) and PhN(Tf)\(_{2}\)\(^{4}\) were prepared by applying reported protocols.

Synthetic procedures.

Synthetic intermediates that have not been assigned numbers in the text are numbered in the Supporting Information beginning with 40.

Development of Cu(I)-catalyzed cyclization to form dihydropyridine ring.

Synthesis of 20.

A solution of 40\(^5\) (1.03 g, 2.69 mmol) in MeCN (13.5 ml) was added cesium carbonate (1.40 g, 4.30 mmol) and benzene thiol (360 μl, 3.50 mmol) at 0 °C and stirred at room temperature for 4.5 h. The mixture was added H\(_2\)O at 0 °C and extracted with EtOAc. The organic extracts was washed with brine, dried over Na\(_2\)SO\(_4\), and concentrated. The residue was purified by silica-gel column chromatography to afford secondary amine. A solution of the resulting amine in CH\(_2\)Cl\(_2\) (10.0 ml) was treated with methyl propiolate 12a (250 μl, 2.94 mmol) at room temperature for 16.5 h. After concentration of the mixture, the residue was purified by silica-gel column chromatography to afford 20 (665 mg, 2.36 mmol, 88% for 2 steps).

20: \(^1\)H-NMR (500 MHz, CDCl\(_3\)): δ 8.19 (br-s, 1H), 7.59 (d, \(J = 7.9\) Hz, 1H), 7.45 (d, \(J = 13.2\) Hz, 1H), 7.37 (d, \(J = 8.2\) Hz, 1H), 7.21 (ddd, \(J = 8.2, 6.9, 1.3\) Hz, 1H), 7.14 (dd, \(J = 7.9, 6.9, 1.0\) Hz, 1H), 7.00 (d, \(J = 2.2\) Hz, 1H), 4.79 (d, \(J = 13.2\) Hz, 1H), 3.83 (d, \(J = 2.5\) Hz, 2H), 3.69 (s, 3H), 3.54 (t, \(J = 7.6\) Hz, 2H), 3.07 (t, \(J = 7.6\) Hz, 2H), 2.32 (t, \(J = 2.5\) Hz, 1H); \(^{13}\)C-NMR (125 MHz, CDCl\(_3\)): δ 169.96, 150.95, 136.47, 127.26, 122.37, 122.33, 119.71, 118.61, 112.40, 111.48, 86.36, 77.91, 73.61, 50.78, 23.87; HRMS (ESI, \(m/z\)): [M+Na]\(^+\) calcd. for C\(_{17}\)H\(_{18}\)N\(_2\)NaO\(_2\), 305.1260; found, 305.1274.

The \(^1\)H and \(^{13}\)C NMR spectra of 20 are shown in Figure S1 and S2.

**Cu(I)-catalyzed 6-endo cyclization of 20 to form 21.**

A solution of N-propargylamine 20 (57.2 mg, 0.203 mmol) and [Cu(dppf)(MeCN)]PF$_6$ (16.1 mg, 0.0200 mmol) in CH$_2$Cl$_2$ (4.0 ml) was stirred at room temperature for 1 h. After concentration of the mixture, the yield of 21 (0.197 mmol, 97%) was calculated based on $^1$H-NMR using 1,10-phenanthroline as an internal standard. The 1,6-dihydropyridine was difficult to isolate due to instability upon chromatographic separation.

21: $^1$H-NMR (500 MHz, CDCl$_3$): $\delta$ 8.16 (s, 1H), 7.58 (d, $J = 8.20$ Hz, 1H), 7.38 (d, $J = 8.20$ Hz, 1H), 7.22 (ddd, $J = 8.20$, 6.94, 0.95 Hz, 1H), 7.18 (s, 1H), 7.15 (ddd, $J = 8.20$, 6.94, 0.95 Hz, 1H), 7.03 (s, 1H), 6.32 (dq, $J = 10.1$, 1.6 Hz, 1H), 4.98 (dt, $J = 10.1$, 3.2 Hz, 1H), 4.21 (q, $J = 1.6$ Hz, 2H), 3.65 (s, 3H), 3.35 (t, $J = 7.3$ Hz, 2H), 3.03 (t, $J = 7.3$ Hz, 2H); $^{13}$C-NMR (125 MHz, CDCl$_3$): $\delta$ 167.17, 148.11, 136.44, 127.14, 122.82, 122.44, 122.39, 119.70, 118.46, 111.96, 111.52, 109.16, 95.81, 56.59, 50.67, 48.52, 23.45; HRMS (ESI, $m/z$) [M+H]$^+$ calcd. for C$_{17}$H$_{19}$N$_2$O$_2$, 283.1441; found, 283.1444.

The $^1$H NMR and $^{13}$C NMR spectra of 21 are shown in Figure S3 and S4.
Synthesis of *iboga*-type scaffold 23 and (-)-catharanthine, (-)-6.

**Synthesis of tricycle 11a.**

A slurry of 22 (3.04 g, 12.5 mmol) in acetic acid (25.0 ml) was treated with NaBH$_3$CN (1.02 g, 16.2 mmol) in two portion and stirred at room temperature for 5 h. Additional NaBH$_3$CN (175 mg, 2.79 mmol) was then added. After being stirred for 1 h to complete the reaction, the resulting mixture was slowly added conc. HCl aq. and then stirred until gas evolution was stopped. After concentration under reduced pressure, the residue was basified with concentrated aqueous solution of NH$_3$ at 0 °C and extracted with CH$_2$Cl$_2$, dried over Na$_2$SO$_4$, and concentrated. A slurry of 41 (3.56 g, 25.8 mmol), Et$_3$N (2.10 ml, 14.9 mmol) and propargyl bromide 10 (1.39 ml, 16.1 mmol) at r.t. for 27.5 h. After concentration, the residue was added water and extracted with EtOAc. The organic layer was washed with water and brine, dried over Na$_2$SO$_4$, and concentrated. Purification by silica-gel column chromatography afforded 11a (2.16 g, 7.65 mmol, 61% for 2 steps) as a pale yellow crystal.

11a: $^{1}$H-NMR (500 MHz, CDCl$_3$): $\delta$ 8.33 (br-s, 1H), 7.51 (d, $J = 7.9$ Hz, 1H), 7.30 (d, $J = 7.9$ Hz, 1H), 7.16 (m, 1H), 7.11 (m, 1H), 4.02 (dd, $J = 6.6$, 2.5 Hz, 1H), 3.77 (s, 3H), 3.58 (d, $J = 2.5$ Hz, 1H), 3.37 (dd, $J = 12.9$, 6.6 Hz, 1H), 3.14 (dd, $J = 12.9$, 2.5 Hz, 1H), 2.94-3.01 (m, 3H), 2.86-2.94 (m, 1H), 2.25 (t, $J = 2.5$ Hz, 1H); $^{13}$C-NMR (125 MHz, CDCl$_3$): $\delta$ 172.30, 134.94, 132.02, 128.57, 121.78, 119.46, 118.17, 113.80, 110.85, 79.27, 72.95, 56.90, 55.56, 52.54, 49.22, 45.94, 24.63; HRMS (ESI, m/z) [M+H]$^+$ calcd. for C$_{17}$H$_{19}$N$_2$O$_2$, 283.1441; found, 283.1462.

The $^1$H and $^{13}$C NMR spectra of 11a are shown in Figure S5 and S6.

**Synthesis of *iboga*-type scaffold 23.**

A solution of 11a (125 mg, 0.443 mmol) in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (2.2 ml) was treated with methyl propiolate 12a (74 μl, 0.888 mmol) at room temperature for 2 h. The mixture was added saturated aqueous solution of NaHCO$_3$ and extracted with EtOAc. The combined organic extracts were washed with satd. NaHCO$_3$ aq. and brine, dried over Na$_2$SO$_4$, and concentrated. A solution of crude mixture and [Cu(dppf)(MeCN)]PF$_6$ (35.7 mg, 0.0444 mmol) in 1,2-dichloroethane (10.0 ml) was heated at 60 °C for
30 min under microwave irradiation. The mixture was added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 23 (77.4 mg, 0.211 mmol, 48%).

23: ¹H-NMR (500 MHz, CDCl₃): δ 7.78 (br-s, 1H), 7.50 (d, J = 8.2 Hz, 1H), 7.34 (d, J = 7.3 Hz, 1H), 7.25 (d, J = 7.3 Hz, 1H), 7.16 (td, J = 7.3, 1.3 Hz, 1H), 7.11 (td, J = 7.3, 1.3 Hz, 1H), 4.96 (s, 1H), 3.78 (s, 3H), 3.66 (s, 3H), 3.62 (ddd, J = 14.0, 9.8, 4.1 Hz, 1H), 3.35 (ddd, J = 14.0, 4.7, 4.4 Hz, 1H), 3.29 (ddd, J = 16.1, 9.8, 4.4 Hz, 1H), 2.99 (ddd, J = 16.1, 4.7, 4.4 Hz, 1H), 2.95 (m, 1H), 2.93 (br-d, J = 8.2 Hz, 1H), 2.89 (dt, J = 8.8, 2.8 Hz, 1H), 2.70 (dt, J = 13.2, 2.8 Hz, 1H), 1.90 (dd, J = 13.2, 2.2 Hz, 1H); ¹³C-NMR (125 MHz, CDCl₃): δ 174.23, 164.03, 143.71, 139.66, 135.42, 135.18, 129.08, 122.24, 122.24, 119.70, 118.46, 111.03, 110.65, 56.72, 55.51, 52.82, 52.60, 51.82, 48.12, 37.69, 32.04, 21.54; HRMS (ESI, m/z): [M+H]+ calcd. for C₂₁H₂₃N₂O₄, 367.1652; found, 367.1669; The ¹H and ¹³C NMR spectra of 23 are shown in Figure S7 and S8.

Attempts to synthesize iboga-type scaffolds (42, 43) having a substituent at indole-N1 position.

A solution of 13b (79.7 mg, 0.171 mmol) and [Cu(dppf)(MeCN)]PF₆ (13.1 mg, 0.0171 mmol) in 1,2-dichloroethane (3.4 ml) was stirred at 60 °C for 1 h. After being cooled to room temperature, the reaction mixture was analyzed by ¹H-NMR. There was only a trace amount of corresponding iboga-type scaffold 42.

A solution of 13d (64.6 mg, 0.170 mmol) and [Cu(dppf)(MeCN)]PF₆ (13.7 mg, 0.0170 mmol) in 1,2-dichloroethane (3.4 ml) was stirred at 45 °C for 1 h and 60 °C for 11 h. After being cooled to room temperature, the reaction mixture was analyzed by ¹H-NMR. The corresponding iboga-type scaffold 43 was not detected at all.
Synthesis of a chiral ene-yne 34.

A solution of 11a (56.4 mg, 0.200 mmol) and alkyne 12c (46.0 mg, 0.254 mmol) in 1,2-dichloroethane (1.0 ml) was treated with AcOH (12.6 μl, 0.220 mmol) at room temperature for 4 h. The mixture was added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 34 (62.1 mg, 0.134 mmol, 67%).

Diastereo-controlled synthesis of iboga-type scaffold 35.

A solution of 34 (1.70 g, 3.67 mmol) and [Cu(dppf)(MeCN)]PF₆ (439 mg, 0.548 mmol) in 1,2-dichloroethane (73.0 ml) was stirred at 45 °C for 5.5 h. The mixture was added saturated aqueous solution of NaHCO₃, diluted aqueous solution of NH₃ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 35 (810 mg, 1.75 mmol, 48%).

35: ¹H-NMR (500 MHz, CDCl₃): δ 8.13 (br-s, 1H), 7.50 (d, J = 7.9 Hz, 1H), 7.27 (d, J = 8.2 Hz, 1H), 7.16 (ddd, J = 8.2, 6.9, 1.3 Hz, 1H), 7.11 (ddd, J = 7.9, 6.9, 1.0 Hz, 1H), 7.01 (dd, J = 6.9, 1.0 Hz, 1H), 4.89 (d, J = 1.0 Hz, 1H), 4.68 (ddd, J = 9.1, 6.3, 4.4 Hz, 1H), 4.32 (tt, J = 9.1 Hz, 1H), 4.17 (ddd, J = 9.1, 6.3 Hz, 1H), 3.67 (m, 1H), 3.65 (s, 3H), 3.35 (ddd, J = 13.9, 5.4, 4.7 Hz, 1H), 3.28 (ddd, J = 16.7, 9.8, 4.7 Hz, 1H), 3.00 (dd, J = 16.7, 5.4, 4.4 Hz, 1H), 2.98-2.91 (m, 3H), 2.78 (m, 1H), 2.40 (qn-d, J = 6.9, 4.4 Hz, 1H), 2.04 (dd, J = 12.9, 1.9 Hz, 1H), 0.93 (d, J = 6.9 Hz, 3H), 0.91 (d, J = 6.9 Hz, 3H); ¹³C-NMR (125 MHz, CDCl₃): δ174.23, 166.15, 153.90, 143.46, 140.80, 135.19, 134.96, 129.04, 122.18, 119.58, 118.44, 110.71, 110.64, 110.64, 103.03, 58.14, 56.85, 55.20, 52.74, 52.63, 48.70, 38.87, 32.32, 27.92, 21.64, 17.96, 15.02; HRMS (ESI, m/z): [M+H]+ calcd. for C₂₆H₃₀N₃O₅, 464.2180; found, 464.2163.

The ¹H and ¹³C NMR spectra of 35 are shown in Figure S9 and S10.
Synthesis of methylester 36.

A solution of 35 (759 mg, 1.63 mmol) and anhydrous CeCl₃ (20.0 mg, 0.0811 mmol) in MeOH (16 ml) was stirred at room temperature for 1 h. The mixture was concentrated under reduced pressure and purified by silica-gel column chromatography to afford 36 (478 mg, 1.30 mmol, 80%). The ¹H and ¹³C NMR spectra of 36 were coincident with those of 23.

Synthesis of allylic alcohol 44.

To a solution of 36 (830 mg, 2.27 mmol) in THF, 1 M hexane solution of DIBAL (9.0 ml, 9.00 mmol) was added dropwise at -70 °C. After being stirred at -70 °C for 1 h, excess DIBAL was quenched with EtOAc. The resulting mixture was treated with saturated aqueous solution of Rochelle salt at 0 °C and then vigorously stirred at room temperature for 8 h. The bi-phase solution was extracted with EtOAc and washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 44 (490 mg, 1.45 mmol, 64%).

44: ¹H-NMR (500 MHz, CDCl₃): δ 7.76 (s, 1H), 7.49 (d, J = 7.6 Hz, 1H), 7.25 (d, J = 7.6 Hz, 1H), 7.16 (td, J = 7.6, 1.0 Hz, 1H), 7.11 (td, J = 7.6,1.0 Hz, 1H), 6.22 (dd, J = 6.6, 1.6 Hz, 1H), 4.37 (s, 1H), 4.25 (dd, J = 14.2, 1.6 Hz, 1H), 4.21 (dd, J = 14.2, 1.6 Hz, 1H), 3.75 (s, 3H), 3.57 (ddd, J = 13.6, 9.8, 3.8 Hz, 1H), 3.33 (dt, J = 13.6, 4.7 Hz, 1H), 3.27 (ddd, J = 16.4, 10.1, 4.4 Hz, 1H), 2.97 (ddd, J = 16.6, 4.7, 4.4 Hz, 1H), 2.86 (br-s, 2H), 2.78 (m, 1H), 2.71 (dt, J = 12.9, 2.5 Hz, 1H), 1.86 (dd, J = 12.9, 2.5 Hz, 1H); ¹³C-NMR (125 MHz, CDCl₃): δ 174.24, 147.78, 135.94, 135.16, 129.01, 126.85, 122.21, 119.69, 118.42, 110.83, 110.65, 63.44, 58.34, 55.28, 53.04, 52.80, 49.23, 38.99, 30.89, 21.48; HRMS (ESI, m/z): [M+H]⁺ calced. for C₂₀H₂₂N₂O₃, 339.1703; found, 339.1709.

The ¹H and ¹³C NMR spectra of 44 are shown in Figure S11 and S12.
Total synthesis of (−)-catharanthine: (−)-6.

A solution of 44 (64.9 mg, 0.192 mmol) in CH₂Cl₂ (1.0 ml) was treated with Et₃N (70 µl, 0.501 mmol) and diphenyl chlorophosphate (79 µl, 0.384 mmol) at 0 °C. Reaction mixture was allowed to warm to room temperature and stirred for 4 h. The reaction mixture was added saturated aqueous solution of NaHCO₃ at 0 °C and extracted with EtOAc. The combined organic extracts were washed with water and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 37 (88.4 mg, 0.155 mmol, 81%). To a solution of 37 (69.3 mg, 0.121 mmol) and Fe(acac)₃ (21.0 mg, 0.0607 mmol) in THF (1.2 ml), 3 M Et₂O solution of methyl magnesium bromide (240 µl, 0.726 mmol) was added dropwise at -60 °C and stirred at the same temperature for 40 min. Excess methyl magnesium bromide was quenched with EtOAc. The resulting reaction mixture was poured into ice-cooled saturated aqueous solution of NH₄Cl. This solution was basified with saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford (−)-catharanthine: (−)-6 (15.8 mg, 0.0470 mmol, 39%). The absolute configuration was determined based on the optical rotation [(−)-catharanthine 6: [α]D = -28.4 (c 1.0, CHCl₃); literature data ⁶ for (+)-catharanthine: [α]D²⁷ = +29.8 (CHCl₃)].

(−)-catharanthine 6: ¹H-NMR (500 MHz, CDCl₃): δ 7.61 (br-s, 1H), 7.49 (d, J = 7.6 Hz, 1H), 7.24 (d, J = 7.6 Hz, 1H), 7.15 (t, J = 7.6 Hz, 1H), 7.10 (t, J = 7.6 Hz, 1H), 5.93 (d, J = 5.0 Hz, 1H), 4.17 (s, 1H), 3.73 (s, 3H), 3.56 (ddd, J = 14.2, 10.7, 3.5 Hz, 1H), 3.38 (dt, J = 14.2, 4.4 Hz, 1H), 3.29 (ddd, J = 16.4, 10.7, 4.4 Hz, 1H), 2.96 (dt, J = 16.7, 4.1 Hz, 1H), 2.80-2.88 (m, 2H), 2.68-2.77 (m, 2H), 2.30 (m, 1H), 2.10 (m, 1H), 1.78 (d, J = 11.0 Hz, 1H), 1.06 (t, J = 7.3 Hz, 3H); ¹³C-NMR (125 MHz, CDCl₃): δ 174.32, 149.60, 136.63, 135.13, 129.22, 123.72, 122.03, 119.62, 118.37, 110.91, 110.59, 62.05, 55.63, 53.20, 52.48, 49.48, 38.87, 30.93, 26.34, 21.54, 10.80; HRMS (ESI, m/z): [M+H]⁺ calcd. for C₂₁H₂₅N₂O₂, 337.1911; found, 337.1915.

The ¹H and ¹³C NMR spectra of (−)-6 are shown in Figure S13 and S14.

Synthesis of *aspidosperma*-type scaffold 25 and (±)-vincadifformine 32

An attempt to synthesize *aspidosperma*-type scaffold 25a.

A solution of 11a (359 mg, 1.27 mmol) in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (6.0 ml) was treated with methyl propiolate 12a (212 μl, 2.55 mmol) at room temperature for 2 h. The mixture was added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 13a (370 mg, 1.01 mmol, 80 %). Since 13a was prone to dimerization, purified 13a was immediately used for the following reaction.

A solution of 13a (370 mg, 1.01 mmol) and [Cu(dppf)(MeCN)]PF₆ (138 mg, 0.172 mmol) in CH₂Cl₂ (20.0 ml) was stirred at room temperature for 70 min. Reaction mixture was added CH₂Cl₂ (20.0 ml) and then cooled to -50 °C. The resulting solution was treated with (iPr)₂NEt (700 μl, 4.02 mmol) and TBSOTf (850 μl, 3.74 mmol) at -50 °C. After being stirred for 80 min at the same temperature, the mixture was allowed to warm to -7 °C and stirred for 88.5 h. The mixture was added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 12.9 mg of 25a that contains inseparable impurity (<5% yield).

25a: 

1H-NMR (500 MHz, CDCl₃): δ 8.99 (br-s, 1H), 7.29 (d, J = 7.5 Hz, 1H), 7.14 (td, J = 7.7, 1.1 Hz, 1H), 6.91 (td, J = 7.5, 0.9 Hz, 1H), 6.81 (d, J = 7.7 Hz, 1H), 5.91 (ddd, J = 9.7, 4.8, 1.6 Hz, 1H), 5.83 (ddd, J = 9.7, 2.0, 1.6 Hz, 1H), 3.75 (s, 3H), 3.50 (ddd, J = 16.3, 4.8, 1.6 Hz, 1H), 3.42 (d, J = 1.8 Hz, 1H), 3.32 (s, 3H), 3.25 (dt, J = 16.3, 1.6 Hz, 1H), 3.10 (dd, J = 14.7, 1.8 Hz, 1H), 3.07 (dd, J = 8.4, 6.3 Hz, 1H), 2.81 (ddd, J = 11.3, 8.4, 4.5 Hz, 1H), 2.61 (d, J = 14.7 Hz, 1H), 2.03 (td, J = 11.3, 6.3 Hz, 1H), 1.85 (dd, J = 11.3, 4.5 Hz, 1H); 13C-NMR (125 MHz, CDCl₃): δ 174.27, 168.67, 167.32, 142.96, 138.31, 128.44, 128.18, 127.63, 121.18, 121.01, 109.43, 91.43, 66.43, 55.95, 51.74, 51.61, 51.21, 50.85, 50.62, 44.30, 29.79; HRMS (ESI, m/z): [M+H]+ calcd. for C₂₁H₂₃N₂O₄, 367.1652; found, 367.1663.

The 1H and 13C NMR spectra of 25a are shown in Figure S15 and S16.
Synthesis of \((E)-\text{tert}-\text{butyl}-3-(2-((3\text{-methoxy}-3\text{-oxoprop-1-en-1-yl})(\text{prop-2-yn-1-yl})\text{amino})\text{ethyl}})-2-(3\text{-methoxy}-3\text{-oxoprop-1-en-2-yl})-1\text{H-indole-1-carboxylate} (13b)\).

\[
\begin{align*}
11a & \xrightarrow{\text{Boc}_2\text{O, Et}_3\text{N, cat. DMAP}} \xrightarrow{\text{MeCN}} 11b & \xrightarrow{\text{O Me, CF}_3\text{CH}_2\text{OH, 1,2-dichloroethane}} 13b
\end{align*}
\]

To a solution of 11a (712 mg, 2.52 mmol) in MeCN (10.0 ml), Et$_3$N (426 μl, 3.05 mmol), Boc$_2$O (661 mg, 3.03 mmol) and a catalytic amount of 4-dimethylaminopyridine (DMAP) was added. After being stirred at room temperature for 20 min, the reaction mixture was concentrated under reduced pressure. The residue was purified by silica-gel column chromatography to afford 11b (929 mg, 2.43 mmol, 96%). The resulting 11b (398 mg, 1.04 mmol) was then dissolved in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (5.0 ml) and treated with methyl propiolate 12a (172 μl, 2.07 mmol) at room temperature for 12.5 h. The mixture was concentrated under reduced pressure and purified by silica-gel column chromatography to afford 13b (453 mg, 0.971 mmol, 93%).

13b: \(^1\text{H}-\text{NMR} (500 \text{ MHz, CDCl}_3): \delta 8.14 (d, J = 8.2 \text{ Hz, 1H}), 7.55 (d, J = 7.6 \text{ Hz, 1H}), 7.38 (d, J = 13.2 \text{ Hz, 1H}), 7.35 (td, J = 8.2, 1.0 \text{ Hz, 1H}), 7.28 (td, J = 8.2, 1.0 \text{ Hz, 1H}), 6.63 (d, J = 1.3 \text{ Hz, 1H}), 5.80 (d, J = 1.3 \text{ Hz, 1H}), 4.72 (d, J = 13.2 \text{ Hz, 1H}), 3.74 (s, 3H), 3.72 (br-s, 2H), 3.68 (s, 3H), 3.43 (t, J = 7.3 \text{ Hz, 2H}), 2.99 (br-s, 2H), 2.29 (t, J = 2.5 \text{ Hz, 1H}), 1.60 (s, 9H); \(^{13}\text{C}-\text{NMR} (125 \text{ MHz, CDCl}_3): \delta 169.67, 166.25, 150.53, 150.10, 135.81, 134.08, 132.83, 129.07, 128.28, 125.27, 123.06, 118.85, 117.61, 115.96, 86.88, 84.68, 77.77, 73.68, 52.33, 50.76, 28.13; \text{HRMS (ESI, } m/z): [\text{M+Na}]^+ \text{ calcd. for C}_{26}\text{H}_{30}\text{N}_2\text{O}_6\text{Na, 489.1996; found, 489.2002.}}\)

The \(^1\text{H} \text{ and } \(^{13}\text{C} \text{ NMR spectra of } 13b \text{ are shown in Figure S17 and S18.}\)

Synthesis of \(\text{tert}-\text{butyl} \ 2-(3\text{-methoxy}-3\text{-oxoprop-1-en-2-yl})-3-(2-(5\text{-methoxycarbonyl})-3,4\text{-dihydro}\text{ pyridine-1(2H)-yl})\text{ethyl}-1\text{H-indole-1-carboxylate} (24b)\).

\[
\begin{align*}
13b & \xrightarrow{[\text{Cu(dppf)(MeCN)}]\text{PF}_6 \ (10 \text{ mol\%})} \xrightarrow{\text{CH}_2\text{Cl}_2, \text{r.t.}} 14b & \xrightarrow{\text{H}_2, 10\% \text{ Pd/C (25 mol\%)}} 24b
\end{align*}
\]

A solution of 13b (1.79 g, 3.84 mmol) and [Cu(dppf)(MeCN)]PF$_6$ (309 mg, 0.385 mmol) in CH$_2$Cl$_2$ (38.0 ml) was stirred at room temperature for 4 h and then concentrated. The residue was dissolved in MeOH (38.0 ml) with 10% Pd/C (1.02 g, 0.960 mmol) and stirred at room temperature for 43.5 h under H$_2$ atmosphere. The mixture was filtrated through the Celite and washed with MeOH. The filtrate was concentrated and purified by silica-gel column chromatography to afford 24b (1.25 g, 2.67 mmol, 70%).
24b: $^1$H-NMR (500 MHz, CDCl$_3$): $\delta$ 8.14 (d, $J = 8.5$ Hz, 1H), 7.53 (d, $J = 7.6$ Hz, 1H), 7.35 (ddd, $J = 8.5$, 7.3, 1.3 Hz, 1H), 7.30 (s, 1H), 7.28 (t, $J = 7.6$ Hz, 1H), 6.64 (d, $J = 1.6$ Hz, 1H), 5.78 (d, $J = 1.6$ Hz, 1H), 3.72 (s, 3H), 3.66 (s, 3H), 3.31 (t, $J = 7.6$ Hz, 2H), 3.07 (t, $J = 5.7$ Hz, 2H), 2.91 (br-s, 2H), 2.23 (t, $J = 6.3$ Hz, 2H), 1.76 (m, 2H), 1.60 (s, 9H); $^{13}$C-NMR (125 MHz, CDCl$_3$): $\delta$ 169.10, 166.31, 150.21, 145.62, 135.88, 134.20, 132.64, 129.20, 128.04, 125.25, 122.96, 118.91, 117.93, 115.97, 94.67, 84.67, 56.08, 52.32, 50.64, 46.47, 28.17, 24.40, 21.42, 20.10; HRMS (ESI, $m/z$): [M+Na]$^+$ calcd. for C$_{26}$H$_{32}$N$_2$O$_6$Na, 491.2153; found, 491.2260.

The $^1$H and $^{13}$C NMR spectra of 24b are shown in Figure S19 and S20.

**Synthesis of aspidosperma-type scaffold 25b.**

![Synthesis of aspidosperma-type scaffold 25b.](image)

A solution of 24b (151 mg, 0.322 mmol) and hydroquinone (10.0 mg, 0.0908 mmol) in toluene/1,2-dichloroethane=3/2 (5.0 ml) was heated at 180 °C for 50 min under microwave irradiation. The reaction mixture was concentrated and purified by silica-gel column chromatography to afford 25b (72.7 mg, 0.197 mmol, 61%).

25b: $^1$H-NMR (500 MHz, CDCl$_3$): $\delta$ 8.88 (br-s, 1H) 7.27 (d, $J = 7.6$ Hz, 1H), 7.11 (td, $J = 7.6$, 1.3 Hz, 1H), 6.90 (td, $J = 7.6$, 1.0 Hz, 1H), 6.77 (d, $J = 7.6$ Hz, 1H), 3.76 (s, 3H), 3.21 (s, 3H), 3.21 (s, 1H), 3.12 (br-dd, $J = 11.4$, 5.7 Hz, 1H), 2.95 (t, $J = 7.3$ Hz, 1H), 2.94 (d, $J = 14.5$ Hz, 1H), 2.78 (dd, $J = 14.5$, 1.9 Hz, 1H), 2.70 (ddd, $J = 11.4$, 8.5, 4.4 Hz, 1H), 2.49 (td, $J = 11.4$, 2.5 Hz, 1H), 2.03 (m, 1H), 1.98 (td, $J = 11.4$, 6.3 Hz, 1H), 1.85 (m, 1H), 1.78 (dd, $J = 11.4$, 4.4 Hz, 1H), 1.54-1.63 (m, 2H); $^{13}$C-NMR (125 MHz, CDCl$_3$): $\delta$ 176.14, 168.92, 167.65, 143.00, 138.45, 127.30, 120.89, 120.73, 109.33, 92.66, 68.12, 56.40, 51.62, 51.24, 51.19, 50.14, 48.81, 45.29, 31.99, 26.52, 22.27; HRMS (ESI, $m/z$): [M+H]$^+$ calcd. for C$_{21}$H$_{25}$N$_2$O$_4$, 369.1809; found, 369.1823.

The $^1$H and $^{13}$C NMR spectra of 25b are shown in Figure S21 and S22.
Synthesis of alcohol 30.

To a solution of 25b (109 mg, 0.296 mmol) in THF (3.0 ml), 1M hexane solution of DIBAL (1.48 ml, 1.48 mmol) was added dropwise at -78 °C. After being stirred for 5 min at the same temperature, the reaction mixture was allowed to warm to 0 °C and stirred for 50 min. The reaction mixture was then cooled to -78 °C and treated with EtOAc at -78 °C to quench the remaining DIBAL. A saturated aqueous solution of Rochelle salt was added at 0 °C, and the resulting mixture was vigorously stirred at room temperature for 11 h and then extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO3 and brine, dried over Na2SO4, and concentrated. The residue was purified by silica-gel column chromatography to afford 30 (87.9 mg, 0.258 mmol, 87%).

30: 1H-NMR (500 MHz, CDCl3): δ 8.87 (br-s, 1H) 7.18 (d, \( J = 7.6 \) Hz, 1H), 7.12 (t, \( J = 7.9 \) Hz, 1H), 6.86 (t, \( J = 7.6 \) Hz, 1H), 6.79 (d, \( J = 7.9 \) Hz, 1H), 3.76 (s, 3H), 3.13 (dd, \( J = 11.0, 3.8 \) Hz, 1H), 2.91-2.97 (m, 2H), 2.75 (d, \( J = 15.5 \) Hz, 1H), 2.57 (ddd, \( J = 11.0, 8.5, 5.0 \) Hz, 1H), 2.55 (s, 1H), 2.46 (td, \( J = 10.7, 3.5 \) Hz, 1H), 2.39 (dd, \( J = 15.5, 1.3 \) Hz, 1H), 2.08 (td, \( J = 11.4, 6.3 \) Hz, 1H), 1.78-1.89 (m, 2H), 1.72 (dd, \( J = 11.7, 4.7 \) Hz, 1H), 1.51-1.63 (m, 2H), 1.03 (t, \( J = 5.4 \) Hz, 1H); 13C-NMR (125 MHz, CDCl3): δ 169.11, 167.39, 143.43, 137.40, 127.83, 121.19, 120.82, 109.56, 92.57, 67.86, 67.11, 55.49, 51.79, 51.30, 50.49, 45.32, 40.78, 31.44, 25.42, 21.74; HRMS (ESI, \( m/z \)): [M+H]+ calcd. for C20H25N2O3, 341.1860; found, 341.1877.

The 1H and 13C NMR spectra of 30 are shown in Figure S23 and S24.

Synthesis of aldehyde 45.

A solution of 30 (20.0 mg, 0.0588 mmol) in DMSO/(iPr)2NEt = 1/1 (600 µl) was treated with SO3·pyridine (37.0 mg, 0.235 mmol) at room temperature for 70 min. The reaction mixture was diluted with EtOAc, saturated aqueous solution of NaHCO3, and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO3 and brine, dried over Na2SO4, and concentrated. The residue was purified by silica-gel column chromatography to afford 45 (21.3 mg, quant.).

45: 1H-NMR (500 MHz, CDCl3): δ 9.22 (s, 1H), 8.82 (br-s, 1H), 7.28 (d, \( J = 7.6 \) Hz, 1H), 7.12 (td, \( J = 7.7, 1.3 \) Hz, 1H), 6.91 (td, \( J = 7.6, 0.6 \) Hz, 1H), 6.77 (d, \( J = 7.7 \) Hz, 1H), 3.77 (s, 3H), 3.33 (s, 1H), 3.15 (m, 1H),
3.00 (ddd, $J = 8.5$, 6.6, 1.3 Hz, 1H), 2.95 (d, $J = 15.5$ Hz, 1H), 2.78 (dd, $J = 15.1$, 1.9 Hz, 1H), 2.76 (m, 1H), 2.55 (td, $J = 11.4$, 3.2 Hz, 1H), 2.04 (ddd, $J = 11.4$, 10.7, 6.3 Hz, 1H), 1.77-1.88 (m, 3H), 1.63 (m, 1H), 1.41 (td, $J = 14.3$, 4.7 Hz, 1H); $^{13}$C-NMR (125 MHz, CDCl$_3$): δ 205.10, 168.39, 168.27, 142.85, 137.34, 127.68, 121.23, 121.14, 109.55, 92.22, 67.35, 55.97, 52.25, 51.89, 51.28, 49.47, 45.46, 29.02, 25.47, 21.26; HRMS (ESI, m/z): [M+H]$^+$ calcd. for C$_{20}$H$_{23}$N$_2$O$_3$, 339.1703; found, 339.1723.

The $^1$H and $^{13}$C NMR spectra of 45 are shown in Figure S25 and S26.

**Synthesis of terminal olefin 31.**

![Synthesis of terminal olefin 31.](image)

To a solution of methyltriphenylphosphonium bromide (210 mg, 0.588 mmol) in THF (1.0 ml), 1 M THF solution of NaHMDS (529 μl, 0.529 mmol) was added dropwise at -45 °C. After being stirred at the same temperature for 10 min, the mixture was allowed to warm to room temperature and stirred for 20 min. After being cooled to -45 °C again, 45 (19.9 mg, 0.0588 mmol) in THF (1.0 ml) was added via cannula. After 10 min, the reaction mixture was warmed to 0 °C and stirred for 25 min. The mixture was added saturated aqueous solution of NaHCO$_3$ and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO$_3$ and brine, dried over Na$_2$SO$_4$, and concentrated. The residue was purified by silica-gel column chromatography to afford 31 (11.6 mg, 0.0345 mmol, 59%).

31: $^1$H-NMR (500 MHz, CDCl$_3$): δ 8.85 (br-s, 1H), 7.23 (d, $J = 7.6$ Hz, 1H), 7.11 (t, $J = 7.6$, 1H), 6.86 (t, $J = 7.6$, 1H), 6.77 (d, $J = 7.6$ Hz, 1H), 5.37 (dd, $J = 18.0$, 11.0 Hz, 1H), 4.65 (d, $J = 11.0$ Hz, 1H), 4.46 (d, $J = 18.0$ Hz, 1H), 3.76 (s, 3H), 3.14 (br-d, $J = 11.1$ Hz, 1H), 2.96 (d, $J = 14.5$ Hz, 1H), 2.94 (m, 1H), 2.84 (s, 1H), 2.64 (ddd, $J = 11.4$, 8.2, 4.7 Hz, 1H), 2.45 (td, $J = 10.0$, 2.8 Hz, 1H), 2.33 (dd, $J = 14.5$, 1.6 Hz, 1H), 2.03 (td, $J = 11.4$, 6.3 Hz, 1H), 1.86 (m, 1H), 1.70-1.77 (m, 2H), 1.56 (m, 1H), 1.42 (td, $J = 13.6$, 4.7 Hz, 1H); $^{13}$C-NMR (125 MHz, CDCl$_3$): δ 169.21, 167.84, 145.27, 143.37, 137.94, 127.56, 120.92, 120.67, 113.52, 109.48, 93.70, 70.61, 55.92, 51.84, 51.13, 50.52, 45.76, 42.58, 35.59, 28.66, 22.61; HRMS (ESI, m/z): [M+H]$^+$ calcd. for C$_{20}$H$_{23}$N$_2$O$_3$, 339.1911; found, 339.1925.

The $^1$H and $^{13}$C NMR spectra of 31 are shown in Figure S27 and S28.
Total synthesis of (±)-vincadifformine 32.

A suspension of 31 (26.0 mg, 0.0773 mmol) in MeOH (2.0 ml) with 10% Pd/C (28.0 mg, 0.0267 mmol) was stirred at room temperature for 2 h 40 min under H₂ atmosphere. The mixture was filtrated through the Celite and washed with MeOH. The filtrate was concentrated and purified by silica-gel column chromatography to afford (±)-vincadifformine 32 (20.1 mg, 0.0594 mmol, 77%).

(±)-vincadifformine 32: ¹H-NMR (500 MHz, CDCl₃): δ 8.90 (br-s, 1H), 7.18 (d, J = 7.3 Hz, 1H), 7.12 (t, J = 7.9 Hz, 1H), 6.85 (t, J = 7.3 Hz, 1H), 6.79 (d, J = 7.9 Hz, 1H), 3.76 (s, 3H), 3.11 (m, 1H), 2.91 (dd, J = 8.2, 6.6 Hz, 1H), 2.72 (d, J = 15.1 Hz, 1H), 2.55 (ddd, J = 11.4, 8.2, 4.7 Hz, 1H), 2.44 (s, 1H), 2.40 (td, J = 10.7, 2.8 Hz, 1H), 2.27 (dd, J = 15.1, 1.3 Hz, 1H), 2.04 (td, J = 11.4, 6.6 Hz, 1H), 1.77-1.88 (m, 2H), 1.69 (dd, J = 11.4, 4.7 Hz, 1H), 1.54 (m, 1H), 1.25 (m, 1H), 0.97 (m, 1H), 0.62 (m, 1H), 0.57 (t, J = 6.9 Hz, 3H); ¹³C-NMR (125 MHz, CDCl₃): δ 169.36, 168.01, 143.43, 138.08, 127.55, 121.15, 120.61, 109.46, 92.79, 72.83, 55.60, 51.86, 51.12, 50.82, 45.42, 38.31, 33.03, 29.44, 25.67, 22.30, 7.27; HRMS (ESI, m/z): [M+H]⁺ calcd. for C₂₁H₂₇N₂O₂, 339.2067; found, 339.2074.

The ¹H and ¹³C NMR spectra of 32 are shown in Figure S29 and S30.

Synthesis of andranginine-type scaffold 27 and (±)-andranginine 7.

Synthesis of ene-yne 13c.

A solution of 11a (565 mg, 2.00 mmol) and Teoc-Im (640 mg, 3.01 mmol) in MeCN (6.7 ml) was treated with DBU (149 μl, 0.998 mmol) at room temperature for 23.5 h. The reaction mixture was concentrated and purified by silica-gel column chromatography to afford 11c (560 mg). The resulting 11c (560 mg, 1.31 mmol) was then dissolved in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (5.2 ml) and treated with 4-(trimethylsilyl)-3-butyne-2-one 12b (434 μl, 2.60 mmol) at 45 °C for 15 h. The mixture was concentrated and purified by silica-gel column chromatography to afford 13c (586 mg, 1.18 mmol, 59% for 2 steps from 11a).

13c: 1H-NMR (500 MHz, CDCl3): δ 8.16 (d, J = 8.2 Hz, 1H), 7.55 (d, J = 7.6 Hz, 1H), 7.37 (td, J = 8.2, 1.3 Hz, 1H), 7.36 (m, 1H), 7.30 (td, J = 7.6, 0.6 Hz, 1H), 6.62 (d, J = 1.3 Hz, 1H), 5.79 (d, J = 1.3 Hz, 1H), 5.17 (d, J = 12.9 Hz, 1H), 4.44 (m, 2H), 3.76 (br-s, 2H), 3.76 (s, 3H), 3.48 (t, J = 7.3 Hz, 2H), 3.02 (br-s, 2H), 2.31 (t, J = 2.2 Hz, 1H), 2.08 (s, 3H), 1.17 (m, 2H), 0.07 (s, 9H); 13C-NMR (125 MHz, CDCl3): δ 195.73, 166.38, 151.63, 150.25, 135.65, 134.04, 132.98, 129.22, 128.51, 125.50, 123.34, 118.87, 117.95, 116.16, 98.86, 73.97, 70.48, 66.26, 52.46, 28.32, 17.71, -1.44; HRMS (ESI, m/z): [M+Na]+ calcd. for C27H34N2O5NaSi, 517.2129; found, 517.2117.

The 1H and 13C NMR spectra of 13c are shown in Figure S31 and S32.

Synthesis of andranginine-type scaffold 27.

A solution of 13c (50.0 mg, 0.101 mmol) and [Cu(dppf)(MeCN)]PF6 (16.2 mg, 0.0202 mmol) in 1,2-dichloroethane (1.0 ml) was stirred at 45 °C for 3 h. After concentration under reduced pressure, the residue was dissolved in THF (3.0 ml) and treated with 1 M THF solution of tetrabutylammonium fluoride.

(150 μl, 0.150 mmol) at 0 °C for 25 min. The mixture was added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The organic extracts were washed with saturated aqueous solution of NaHCO₃ and NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The crude mixture was then dissolved in 1,2-dichloroethane (2.0 ml) and treated with (iPr₂)NEt (52 μl, 0.298 mmol) and TIPSOTf (60 μl, 0.223 mmol) at room temperature. After being stirred for 1 h at the same temperature, the reaction mixture was added saturated aqueous solution of NaHCO₃ at 0 °C and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford 27 (14.6 mg, 0.0288 mmol, 29%).

27: ¹H-NMR (500 MHz, CDCl₃): δ 8.11 (br-s, 1H), 7.49 (d, J = 7.6 Hz, 1H), 7.33 (d, J = 7.6 Hz, 1H), 7.18 (t, J = 7.6 Hz, 1H), 7.10 (t, J = 7.6 Hz, 1H), 6.66 (d, J = 10.1 Hz, 1H), 5.71 (br-dd, J = 10.1, 5.0 Hz, 1H), 3.81 (s, 1H), 3.68 (s, 3H), 3.62 (d, J = 17.0 Hz, 1H), 3.47 (dd, J = 14.8, 11.0 Hz, 1H), 3.25-3.32 (m, 2H), 3.11 (dd, J = 16.7, 11.0 Hz, 1H), 2.73 (dd, J = 16.7, 5.0 Hz, 1H), 2.66 (dd, J = 12.6, 3.8 Hz, 1H), 2.45 (m, 1H), 2.23 (br-dd, J = 17.3, 5.0 Hz, 1H), 2.17 (td, J = 12.6, 5.0 Hz, 1H), 1.14-1.21 (m, 3H), 1.12 (s, 12H), 1.11 (s, 6H); ¹³C-NMR (125 MHz, CDCl₃): δ 172.29, 143.16, 136.60, 135.15, 127.77, 123.34, 122.25, 121.89, 119.60, 118.56, 115.61, 114.03, 64.88, 55.00, 54.06, 52.65, 48.13, 33.83, 27.83, 18.21, 18.16, 17.72, 13.33; HRMS (ESI, m/z): [M+H⁺] calcd. for C₃₀H₄₃N₂O₃Si, 507.3037; found, 507.3054.

The ¹H and ¹³C NMR spectra of 27 are shown in Figure S33 and S34.

Total synthesis of (±)-andranginine 7.

To a glass vial (Biotage microwave vial 0.5-2 ml) containing cesium fluoride (77.5 mg, 0.510 mmol) and N-phenyl-bis(trifluoromethanesulfonimide) (109 mg, 0.305 mmol), a solution of 27 (51.5 mg, 0.102 mmol) in 1,2-dimethoxyethane (2.0 ml) was added at room temperature. The mixture was vigorously stirred for 4 h in the glass vial sealed with a cap (Biotage caps and septa). The mixture was then cooled to -78 °C, and additional cesium fluoride (130 mg, 0.855 mmol) and N-phenyl-bis(trifluoromethanesulfonimide) (100 mg, 0.280 mmol) were added and stirred at room temperature for 2 h to complete the reaction. After being cooled to -78 °C, the cap of the vial was opened. The vial was allowed to warm to room temperature, and the mixture was poured to a stirred mixture of diethyl ether and phosphate buffer (pH 7.2) at 0 °C. The resulting mixture was extracted with EtOAc, washed with saturated aqueous solution of NaHCO₃ and brine, dried over Na₂SO₄, and concentrated. The residue was roughly purified with column chromatography using Florisil to afford vinyl triflate 33, which was directly used for next reaction without further purification.
To a glass vial (Biotage microwave vial 0.5-2 ml) containing Pd(PPh₃)₄ (11.6 mg, 0.0100 mmol), a solution of 33, triethylamine (48 μl, 0.350 mmol) and formic acid (7.5 μl, 0.199 mmol) in DMF (1.5 ml) was added and stirred at 50 °C for 25 min under microwave irradiation. The resulting mixture was diluted with EtOAc, added saturated aqueous solution of NaHCO₃ and extracted with EtOAc. The combined organic extracts were washed with water and brine, dried over Na₂SO₄, and concentrated. The residue was purified by silica-gel column chromatography to afford (±)-andranginine 7 (15.6 mg, 0.0467 mmol, 46% for 2 steps).

(±)-andranginine 7: ¹H-NMR (500 MHz, CDCl₃): δ 8.16 (br-s, 1H), 7.50 (d, J = 7.9 Hz, 1H), 7.35 (d, J = 7.9 Hz, 1H), 7.19 (t, J = 7.9 Hz, 1H), 7.11 (t, J = 7.9 Hz, 1H), 6.11 (d, J = 9.5 Hz, 1H), 5.82 (dd, J = 9.5, 5.0 Hz, 1H), 5.61 (s, 1H), 3.72 (s, 1H), 3.67 (s, 3H), 3.64 (d, J = 17.0 Hz, 1H), 3.46 (dd, J = 14.8, 11.4 Hz, 1H), 3.31 (dd, J = 17.0, 5.0 Hz, 1H), 3.28 (dd, J = 14.8, 5.0 Hz, 1H), 3.12 (dd, J = 16.7, 11.0 Hz, 1H), 2.76 (dd, J = 16.7, 5.0 Hz, 1H), 2.63 (br-dt, J = 12.6, 2.8 Hz, 1H), 2.28 (br-s, 2H), 2.11 (ddd, J = 12.6, 11.0, 6.9 Hz, 1H);
¹³C-NMR (125 MHz, CDCl₃): δ 171.94, 136.91, 135.14, 135.04, 128.07, 127.77, 126.08, 122.51, 122.23, 119.59, 118.54, 115.12, 110.80, 64.90, 55.02, 54.14, 52.53, 48.27, 34.13, 22.94, 17.94; HRMS (ESI, m/z): [M+H]⁺ calcd. for C₂₁H₂₃N₂O₂, 335.1754; found, 335.1770.

The ¹H and ¹³C NMR spectra of (±)-7 are shown in Figure S35 and S36. The X-ray crystallographic data of (±)-7 (CCDC-936931) is shown in Figure S49 and Table S1.
Synthesis of ngouniensine-type scaffold 28.

A solution of 11a (121 mg, 0.429 mmol) in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (2.1 ml) was treated with methyl propiolate 12a (71 μl, 0.857 mmol) at room temperature for 2 h 20 min. The mixture was added saturated aqueous solution of NaHCO3 and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO3 and brine, dried over Na2SO4, and concentrated. This crude mixture and [Cu(dppf)(MeCN)]PF6 (34.4 mg, 0.0428 mmol) was then dissolved in 1,2-dichloroethane and heated at 120 °C for 20 min under microwave irradiation. The mixture was added saturated aqueous solution of NaHCO3 and extracted with EtOAc. The combined organic extracts were washed with saturated aqueous solution of NaHCO3 and brine, dried over Na2SO4, and concentrated. The residue was purified by silica-gel column chromatography to afford 28 (89.2 mg, 0.243 mmol, 57%). The relative stereochemistry of 28 was assigned based on the comparison of NMR spectra of 28 and crystalline equivalent 48 bearing a phenyl substituent instead of methyl ester group in 28. The data for X-ray crystallographic analysis of 48 was provided in this supporting information. The crystalline 48 was synthesized from previously reported vinylindole 46 by applying similar conversions of the corresponding ene-yne 47, Cu(I)-catalyzed formation of dihydropyridine ring followed by microwave irradiation.

**28**: $^1$H-NMR (500 MHz, CDCl3): $\delta$ 7.95 (br-s, 1H), 7.56 (s, 1H), 7.49 (d, $J = 7.9$ Hz, 1H), 7.29 (d, $J = 7.9$ Hz, 1H), 7.18 (ddd, $J = 7.9$, 6.9, 1.0 Hz, 1H), 7.13 (ddd, $J = 7.9$, 6.9, 1.0 Hz, 1H), 6.71 (d, $J = 9.8$ Hz, 1H), 5.34 (d, $J = 4.7$ Hz, 1H), 4.84 (dd, $J = 9.8$, 4.7 Hz, 1H), 3.87 (ddd, $J = 13.2$, 6.3, 4.1 Hz, 1H), 3.83 (s, 3H), 3.72 (s, 3H), 3.55 (ddd, $J = 13.2$, 9.5, 3.5 Hz, 1H), 3.21 (ddd, $J = 16.1$, 6.3, 3.5 Hz, 1H), 3.07 (ddd, $J = 16.1$, 9.5, 4.1 Hz, 1H), 1.61 (s, 3H); $^{13}$C-NMR (125 MHz, CDCl3): $\delta$ 173.19, 166.84, 148.14, 135.70, 135.20, 128.23, 125.94, 122.43, 119.86, 118.11, 110.95, 110.62, 107.40, 99.07, 62.80, 58.93, 57.80, 52.88, 50.93, 24.84, 17.90; HRMS (ESI, $m/z$): [M+H]$^+$ calcd. for C$_{21}$H$_{23}$N$_2$O$_4$, 367.1652; found, 367.1668.

The $^1$H and $^{13}$C NMR spectra of 28 are shown in Figure S37 and S38.

**48**: $^1$H-NMR (500 MHz, CDCl3): $\delta$ 7.64 (s, 1H), 7.52 (m, 1H), 7.40-7.45 (m, 2H), 7.37-7.40 (m, 1H), 7.33-7.37 (m, 2H), 7.16 (br-s, 1H), 7.09-7.13 (m, 3H), 6.49 (dd, $J = 10.1$, 0.6 Hz, 1H), 4.95 (d, $J = 5.0$ Hz, 1H), 4.12 (dd, $J = 10.1$, 5.0 Hz, 1H), 4.02 (ddd, $J = 13.6$, 4.7, 4.1 Hz, 1H), 3.71 (s, 3H), 3.52 (ddd, $J = 13.6$, 11.4, 2.8 Hz, 1H), 3.31 (ddd, $J = 16.1$, 4.7, 2.8 Hz, 1H), 3.16 (ddd, $J = 16.1$, 11.4, 4.1 Hz, 1H), 1.70 (s, 3H); $^{13}$C-NMR (125 MHz, CDCl3): $\delta$ 167.06, 147.67, 141.55, 140.56, 134.65, 128.90, 128.60, 128.49, 127.72, 123.92, 121.89, 119.55, 117.97, 110.66, 108.76, 98.64, 67.90, 58.49, 55.37, 50.86, 26.35, 19.27; HRMS (ESI, $m/z$): detected as oxidized pyridinium salt [M]$^+$ calcd. for C$_{25}$H$_{23}$N$_2$O$_2$, 383.1754; found, 383.1755.

The $^1$H and $^{13}$C NMR spectra of 48 are shown in Figure S39 and S40. The X-ray crystallographic data of 48 (CCDC-941006) is shown in Figure S50 and Table S2.

Conversion of iboga-type scaffold 23 to ngouniensine-type scaffold 28.

A solution of 23 (81.6 mg, 0.223 mmol) in 1,2-dichloroethane (5.2 ml) was heated at 120 °C for 50 min under microwave irradiation. After concentration, the residue was purified by silica-gel column chromatography to afford 28 (38.2 mg, 0.104 mmol, 47%).
Plausible mechanisms for the formation of ngouniensine-type scaffold 28.

Scheme S1. Plausible mechanisms for the conversion of 14a into 28.

It should be necessary to consider two plausible reaction mechanisms for the intramolecular cyclization of 14a to produce ngouniensine-type scaffold 28. Given the similarity of the DHP unit of 14a to the nicotinamide unit of NADH, we assumed one possibility (path A) featuring a hydride shift from C6-position of DHP to α,β-unsaturated ester. The resulting zwitterionic intermediate composed of a pyridinium cation and an enolate anion would undergo 7-endo cyclization to afford 28. The other possibility (path B) should be postulated by occurrence of thermal isomerization of 1,6-DHP to 1,4-DHP and subsequent pericyclic ene-type reaction to effect hydride transfer from C4-position of DHP to α,β-unsaturated ester moiety giving 28.

Scheme S2. Deuterium labeling experiments for the conversion of 14a into 28.
To verify the two mechanisms whether the hydride shift could occur from C6 or C4 position of DHP in 14a, we devised deuterium labeling experiments by synthesizing both 14a-D2(C6) and 14a-D1(C4). The doubly deuterated 14a-D2(C6) was synthesized according to the procedure described in the main text (Figure 3) by employing 10-D2 in place of propargyl bromide 10. Followed by assembly of 11a-D2 with 12a, we conducted Cu(I)-catalyzed DHP ring formation and subsequent intramolecular cyclization at 120 °C. The hydride shift from C6 position in 14a-D2(C6) did occur to produce 28-D2 with almost complete site-selectivity (>99% deuterium incorporation into one of hydrogen of the methyl group).

In parallel, with the aim of preparing singly deuterated 14a-D1(C4), we synthesized ene-yne 13e from 11a and applied Bew’s protocol10 for the terminal deuteration of alkynes to produce 13e-D1 (98% deuterium incorporation). While Cu(I)-catalyzed cyclization [13e-D1 → 14e-D1(C4)] caused a slight drop of D/H ratio (98% → 77%), removal of Teoc group and subsequent intramolecular cyclization at 120 °C produced 28-D1. The deuterium label almost completely remained at C4 position of DHP and was not observed in the methyl group.

Taken together, results of the deuterium labeling experiments are consistent with the plausible mechanism (path A) involving the hydride shift and the subsequent 7-endo cyclization to form 28.

**Conversion of 11a-D2 to ngouniensine-type scaffold 28-D2 via 14a-D2(C6).**

A solution of 11a-D2 (60.0 mg, 0.213 mmol, >99% deuterium incorporation) in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (1.0 ml) was treated with methyl propiolate 12a (35 μl, 0.425 mmol) at room temperature for 2 h 20 min. The mixture was diluted with toluene and concentrated. This crude mixture and [Cu(dppf)(MeCN)]PF6 (25.7 mg, 0.0320 mmol) was then dissolved in 1,2-dichloroethane and heated at 120 °C for 45 min under microwave irradiation. The mixture was concentrated and purified by silica-gel column chromatography to afford 28-D2 (31.3 mg, 0.0850 mmol, 40%, >99% deuterium incorporations for the corresponding positions as indicated in the previous page). The 1H NMR spectra of 28-D2 is shown in Figure S41.

**Conversion of 13a-D1 to ngouniensine-type scaffold 28-D1 via 14a-D1(C4).**

A solution of 13e-D110 (90.0 mg, 0.176 mmol, 98% deuterium incorporation) and [Cu(dppf)(MeCN)]PF6 (28.3 mg, 0.0352 mmol) in 1,2-dichloroethane (1.8 ml) was stirred at room temperature for 1.5 h. After concentration of the reaction mixture under reduced pressure, deuterium/hydrogen ratio of DHP (77% deuterium incorporation) was elucidated by 1H-NMR. The residue was then dissolved in THF (1.8 ml) and treated with 1 M THF solution of tetrabutylammonium fluoride (220 μl, 0.220 mmol) at 0 °C for 50 min. The mixture was added saturated aqueous solution of NaHCO3 and extracted with EtOAc. The organic extracts were washed with saturated aqueous solution of NaHCO3 and brine, dried over Na2SO4, and concentrated. The crude mixture was then dissolved into 1,2-dichloroethane (4.0 ml) and heated at 120 °C for 30 min under microwave irradiation. The mixture was concentrated and purified by silica-gel column chromatography to afford 28-D1 (34.5 mg, 0.0939 mmol, 53%, 77% deuterium incorporation).

Synthesis of ene-yne 13e.

A solution of 11a (1.48 g, 5.24 mmol) and Teoc-Im (2.73 g, 12.9 mmol) in MeCN (17.5 ml) was treated with DBU (313 μl, 2.10 mmol) at room temperature for 3 h. After treatment with additional DBU (313 μl, 2.10 mmol), reaction mixture was stirred at room temperature for 1.5 h. The reaction mixture was concentrated and purified by silica-gel column chromatography to afford 11c (1.79 g). The resulting 11c (1.79 g, 4.18 mmol) was then dissolved in 1,2-dichloroethane/2,2,2-trifluoroethanol=1/1 (17.0 ml) and treated with methyl propiolate 12a (700 μl, 8.41 mmol) at room temperature for 20 h. The mixture was concentrated and purified by silica-gel column chromatography to afford 13e (1.85 g, 3.62 mmol, 69% for 2 steps from 11a).

13e: 1H-NMR (500 MHz, CDCl3): δ 8.17 (d, J = 8.2 Hz, 1H), 7.56 (d, J = 7.6 Hz, 1H), 7.39 (d, J = 13.2 Hz, 1H), 7.37 (ddd, J = 8.2, 7.3, 1.3 Hz, 1H), 7.30 (m, 1H), 6.62 (d, J = 1.3 Hz, 1H), 5.79 (d, J = 1.3 Hz, 1H), 4.72 (d, J = 13.2 Hz, 1H), 4.44 (m, 2H), 3.76 (s, 3H), 3.73 (m, 2H), 3.68 (s, 3H), 3.45 (t, J = 7.6 Hz, 2H), 3.00 (br-s, 2H), 2.28 (t, J = 2.5 Hz, 1H), 1.18 (m, 2H), 0.08 (s, 9H); 13C-NMR (125 MHz, CDCl3): δ 169.71, 166.37, 151.65, 150.55, 135.63, 133.97, 132.90, 129.24, 128.53, 125.42, 123.30, 118.92, 118.12, 116.10, 86.84, 77.76, 73.69, 67.30, 66.20, 52.43, 50.80, 17.67, -1.45; HRMS (ESI, m/z): [M+H]+ calcd. for C27H35N2O6Si, 511.2259; found, 511.2259.

The 1H and 13C NMR spectra of 13e are shown in Figure S42 and S43.
Synthesis of *unnatural* tetracyclic scaffold 29.

A solution of 13a (225 mg, 0.614 mmol) and [Cu(dppf)(MeCN)]PF$_6$ (123 mg, 0.153 mmol) in CH$_2$Cl$_2$ (12.3 ml) was stirred at room temperature for 45 min and cooled to 0 °C. Then, a solution of [Ru(bpy)$_3$](BF$_4$)$_2$ (14.6 mg, 0.0307 mmol) in MeNO$_2$ (12.0 ml) was added. The resulting mixture was stirred under 12W fluorescent lamp irradiation (MITSUBISHI/OSRAM EFD15ED/12•HS) at 0 °C for 30 min. The mixture was filtrated through a pad of Florisil and washed with EtOAc. Eluent was concentrated and purified by silica-gel column chromatography to afford 29 (47.3 mg, 0.129 mmol, 21%).

29: $^1$H-NMR (500 MHz, CDCl$_3$): $\delta$ 9.22 (br-s, 1H), 7.50 (d, $J$ = 7.9 Hz, 1H), 7.36 (d, $J$ = 7.9 Hz, 1H), 7.18 (ddd, $J$ = 7.9, 6.9, 1.0 Hz, 1H), 7.12 (ddd, $J$ = 7.9, 6.9, 1.0 Hz, 1H), 6.59 (s, 1H), 6.48 (d, $J$ = 9.1 Hz, 1H), 5.02 (dd, $J$ = 9.1, 6.0 Hz, 1H), 4.17 (m, 1H), 3.98 (dd, $J$ = 12.0 Hz, 1H), 3.79 (s, 3H), 3.65 (ddd, $J$ = 13.9, 5.7, 1.0 Hz, 1H), 3.56 (s, 3H), 3.33 (td, $J$ = 13.9, 4.7 Hz, 1H), 3.20 (ddd, $J$ = 15.1, 4.7, 1.0 Hz, 1H), 2.84 (ddd, $J$ = 15.1, 12.9, 5.7 Hz, 1H), 2.25 (ddd, $J$ = 14.2, 12.0, 10.4 Hz, 1H), 1.67 (dt, $J$ = 14.2, 1.6 Hz, 1H);

$^{13}$C-NMR (125 MHz, CDCl$_3$): $\delta$ 23.73, 38.82, 41.69, 50.70, 52.64, 56.50, 56.70, 100.88, 107.55, 109.70, 111.58, 117.40, 119.67, 121.83, 122.87, 126.70, 132.54, 135.24, 145.62, 166.87, 174.06; HRMS (ESI, m/z): [M+Na]$^+$ calcd. for C$_{21}$H$_{22}$N$_2$O$_4$Na, 389.1472; found, 389.1479.

The $^1$H, $^{13}$C NMR, $^1$H-$^1$H COSY, HMBC and NOESY spectra of 29 are shown in Figure S44 - S48.
The $^1$H, $^{13}$C NMR spectra of synthetic compounds.

Figure S1. A $^1$H-NMR spectrum of 20 in CDCl$_3$. 
Figure S2. A $^{13}$C-NMR spectrum of 20 in CDCl$_3$. 
Figure S3. A $^1$H-NMR spectrum of 21 (reaction mixture without chromatographic purification).
Figure S4. A $^{13}$C-NMR spectrum of 21 (reaction mixture without chromatographic purification).
Figure S5. A $^1$H-NMR spectrum of 11a in CDCl$_3$. 
Figure S6. A $^{13}$C-NMR spectrum of 11a in CDCl$_3$. 
Figure S7 A $^1$H-NMR spectrum of 23 in CDCl$_3$. 
Figure S8. A $^{13}$C-NMR spectrum of 23 in CDCl$_3$. 
Figure S9. A $^1$H-NMR spectrum of 35 in CDCl$_3$. 

Figure 35. A $^1$H-NMR spectrum of 35 in CDCl$_3$. 

Dio: 10.1038/NCHEM.1798
Figure S10. A $^{13}$C-NMR spectrum of 35 in CDCl₃.
Figure S11. A $^1$H-NMR spectrum of 44 in CDCl$_3$. 
Figure S12. A $^{13}$C-NMR spectrum of 44 in CDCl$_3$. 
Figure S13. A $^1$H-NMR spectrum of (−)-6 in CDCl$_3$. 
Figure S14. A $^{13}$C-NMR spectrum of (−)-6 in CDCl$_3$. 
Figure S15. A $^1$H-NMR spectrum of 25a in CDCl$_3$. 
Figure S16. A $^{13}$C-NMR spectrum of 25a in CDCl$_3$. 
Figure S17. A $^1$H-NMR spectrum of 13b in CDCl$_3$. 
Figure S18. A $^{13}$C-NMR spectrum of 13b in CDCl₃.
Figure S19. A $^1$H-NMR spectrum of 24b in CDCl$_3$. 
Figure S20. A $^{13}$C-NMR spectrum of 24b in CDCl₃.
Figure S21. A $^1$H-NMR spectrum of 25b in CDCl$_3$. 
Figure S22. A $^{13}$C-NMR spectrum of 25b in CDCl$_3$. 

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Figure S23. A $^1$H-NMR spectrum of 30 in CDCl$_3$. 
Figure S24. A $^{13}$C-NMR spectrum of 30 in CDCl$_3$. 
Figure S25. A $^1$H-NMR spectrum of 45 in CDCl$_3$. 
Figure S26. A $^{13}$C-NMR spectrum of 45 in CDCl$_3$. 
Figure S27. A $^1$H-NMR spectrum of 31 in CDCl$_3$. 
Figure S28. A $^{13}$C-NMR spectrum of 31 in CDCl$_3$. 
Figure S29. A $^1$H-NMR spectrum of $(\pm)$-32 in CDCl$_3$. 

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Figure S30. A $^{13}$C-NMR spectrum of $(\pm)$-32 in CDCl$_3$. 
Figure S31. A $^1$H-NMR spectrum of $13c$ in CDCl$_3$. 
Figure S32. A $^{13}$C-NMR spectrum of 13c in CDCl$_3$. 
Figure S33. A $^1$H-NMR spectrum of 27 in CDCl$_3$. 
Figure S34. A $^{13}$C-NMR spectrum of 27 in CDCl$_3$. 
Figure S35. A $^1$H-NMR spectrum of (±)-7 in CDCl$_3$. 
Figure S36. A $^{13}$C-NMR spectrum of ($\pm$)-7 in CDCl$_3$. 
Figure S37. A $^1$H-NMR spectrum of 28 in CDCl$_3$. 
Figure S38. A $^{13}$C-NMR spectrum of 28 in CDCl$_3$. 
Figure S39. A $^1$H-NMR spectrum of 48 in CDCl$_3$. 
Figure S40. A $^{13}$C-NMR spectrum of 48 in CDCl$_3$. 
Figure S41. A $^1$H-NMR spectrum of **28-D2** in CDCl$_3$. 
Figure S42. A $^1$H-NMR spectrum of 13e in CDCl$_3$. 
Figure S43. A $^{13}$C-NMR spectrum of 13e in CDCl$_3$. 
Figure S44 A $^1$H-NMR spectrum of 29 in CDCl$_3$. 
Figure S45. A $^{13}$C-NMR spectrum of 29 in CDCl$_3$. 

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The COSY, HMBC, NOESY analysis of compound 29.

Figure S46. A COSY spectrum of 29 in CDCl₃ and indications of key correlations.
Figure S47. A HMBC spectrum of 29 in CDCl₃ and indications of key correlations.
**Figure S48.** A NOESY spectrum of 29 in CDCl₃ and indications of key correlations.
X-ray crystallographic data.

X-ray crystallographic data for 7.

Figure S49. ORTEP representation of X-ray crystallographic structure of 7 (CCDC Registry # 936931).

Table S1. Crystal data and structure refinement for 7.

A. Crystal Data
Empirical Formula C21H22N2O2
Formula Weight 334.42
Crystal Color, Habit colorless, block
Crystal Dimensions 0.260 X 0.200 X 0.190 mm
Crystal System monoclinic
Lattice Type Primitive
Lattice Parameters

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Dcalc 1.366 g/cm³
F000 712.00
μ(MoKα) 0.883 cm⁻¹

B. Intensity Measurements
Diffractometer XtaLAB mini
Radiation: MoKα (λ = 0.71075 Å) graphite monochromated

Voltage, Current: 50kV, 12mA
Temperature: -180.0°C
Detector Aperture: 75 mm (diameter)
Data Images: 2160 exposures

ω oscillation Range (χ=54.0, φ=0.0): -60.0 - 120.0°
Exposure Rate: 128.0 sec./°
Detector Swing Angle: 30.03°
ω oscillation Range (χ=54.0, φ=120.0): -60.0 - 120.0°
Exposure Rate: 128.0 sec./°
Detector Swing Angle: 30.03°
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Exposure Rate: 128.0 sec./°
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Detector Position: 50.06 mm
Pixel Size: 0.146 mm
20max: 54.9°

No. of Reflections Measured: Total: 16361
Unique: 3706 (Rint = 0.0374)

Corrections: Lorentz-polarization
Absorption (trans. factors: 0.840 - 0.983)

C. Structure Solution and Refinement
Structure Solution: Direct Methods
Refinement: Full-matrix least-squares on F2
Function Minimized: Σ w (Fo2 - Fc2)²
Least Squares Weights: w = 1/ [ σ2(Fo2) + (0.0498 . P)² + 0.7109 . P ]
where P = (Max(Fo2,0) + 2Fc2)/3
20max cutoff: 54.9°
Anomalous Dispersion: All non-hydrogen atoms
No. Observations (All reflections): 3706
No. Variables: 227
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Residuals: R (All reflections): 0.0496
Residuals: wR2 (All reflections): 0.1072
Goodness of Fit Indicator: 1.070
Max Shift/Error in Final Cycle: 0.000
Maximum peak in Final Diff. Map: 0.34 e-/Å³
Minimum peak in Final Diff. Map: -0.23 e-/Å³
X-ray crystallographic data for 48.

Figure S50. ORTEP representation of X-ray crystallographic structure of 48 (CCDC Registry # 941006).

Table S2. Crystal data and structure refinement for 48.

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