

Solid-Phase Synthesis of 5-Biphenyl-2-yl-1*H*-tetrazoles

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Supporting Information.

General. Unless otherwise noted, materials and solvents were purchased from commercial suppliers and were used without purification. Rink amide AM resin was purchased from Rapp Polymer (loading of 0.773 mmol/g, 1% cross-linking, 100-200 mesh). The ¹H NMR and ¹³C NMR spectra were recorded on a Bruker 400 MHz NMR spectrometer. Chemical shifts were reported in parts per million referenced to tetramethylsilane (TMS) or CDCl₃. High resolution MS were measured on an AEI (Manchester) MS50 instrument. The LC/MS spectra were obtained on a Hewlett-Packard HP 1100 liquid chromatography system coupled to a Micromass ZMD-400 spectrometer using an Intersil column (ODS-3, 50 x 2.1 mm). The mobile phase was water (A) and acetonitrile (B), both containing 0.1% trifluoroacetic acid. A gradient was used increasing from 10 to 95% B in 9 min followed by a hold at 95% B for 1 min and then reequilibration for 3 min at a flow rate of 0.5 ml/min. The column was maintained at 35 °C. Mass spectra were acquired in either the positive or negative ion mode under electrospray ionisation (ESI). The compound purity was monitored based on the UV absorbency at 214 nm. The LC/MS operation was controlled by MassLynx software and the LC/MS data were processed by OpenLynx software. The library was purified on a Waters LC4000 preparative HPLC system coupled to a Waters 2487 dual absorbance UV/VIS detector and a Micromass/Waters ZQ 2000 mass spectrometer. A Kromasil C₁₈ column (125 x 20 mm) was used for compound separation.¹

Equipment. Solid phase synthesis was performed using either the SAS semi-automated synthesizer from MultisynTech GmbH in 5 ml syringes or the PLS 6 heating/shaking synthesizer made by Advanced ChemTech in 50 ml Falcon polypropylene tubes or the RS6000 heating/shaking reaction station from STEM in 4 ml vials.

(*E/Z*) 2-Ethoxymethylene-3-oxo-butyric acid ethyl ester (7). The title compound was prepared from ethyl acetylacetonate (127.5 ml, 1.0 mol), triethyl orthoformate (166.3 ml, 1.0 mol) and acetic acid anhydride (188.7 ml, 2.0 mol) according to the literature method.² The product was isolated by fractional column distillation (7 mbar, 110-130 °C) as colorless oil (135.5 g, 73%).

4-Amino-5-cyano-2-hydroxy-benzoic acid ethyl ester (8). Into a 1000 ml 3-necked flask equipped with stirbar, reflux condenser and a pressure-equalizing dropping funnel were placed under an atmosphere of argon NaOEt (356 ml, 0.953 mol) as a 21% (w/w) solution in ethanol as well as additional ethanol (120 ml). Within 10 min, malononitrile (30 ml, 0.476 mol) was added dropwise, maintaining the solution at room temperature. During the addition, a white solid

(1) Bauser, M. J. *Chrom. Sci.* **2002**, 40, 292.

(2) Crombie, L.; Games, D. E.; James, A. W. G. *J. Chem. Soc. Perkin I* **1978**, 464.

precipitated. The resulting reaction mixture was stirred for 20 min at room temperature and 2-ethoxymethylene-3-oxo-butyric acid ethyl ester (**7**) (88.5 g, 0.476 mol) in ethanol (250 ml) was added dropwise. Simultaneously, the reaction mixture was heated until refluxing at the end of the addition was reached. The mixture was stirred at reflux for additional 30 min and then allowed to cool to room temperature. The precipitate was filtered, dissolved in water (1500 ml) and acidified to pH 1 with conc. HCl (about 80 ml). During acidification, the product began to precipitate. The solid was filtered, re-crystallized from acetic acid (700 ml), washed with heptane and dried in vacuo to yield the title compound as needles (38.0 g, 39%). HRMS calcd for $C_{10}H_{10}N_2O_3$: 206.0691; found 206.0695. 1H NMR (400 MHz, DMSO- d_6): δ 1.31 (t, $J = 7.1$, 3H), 4.34 (q, $J = 7.1$, 2H), 6.21 (s, 1H), 6.83 (bs, 2H), 7.82 (s, 1H), 10.72 (s, 1H). ^{13}C NMR (100 MHz, DMSO- d_6): δ 13.92, 60.96, 87.30, 99.49, 102.64, 117.02, 137.04, 156.18, 164.11, 167.79.

5-Cyano-2-hydroxy-4-iodo-benzoic acid ethyl ester (9). Into a 500 ml three-necked flask equipped with two pressure-equalizing dropping funnels was placed boron trifluoride diethyl etherate (26.8 ml, 211.6 mmol). Within 40 min, a solution of 4-amino-5-cyano-2-hydroxy-benzoic acid ethyl ester (**8**) (21.8 g, 105.8 mmol) in THF (285 ml) was added dropwise at 0 °C. A solution of *iso*-amyl nitrite (18.5 ml, 137.5 mmol) in THF (30 ml) was added dropwise at -10 °C and stirring was continued for additional 30 min at -10 °C. During addition, the diazonium salt began to precipitate as a yellow solid. Cold diethyl ether (150 ml) was added to complete precipitation maintaining the temperature at about 5 °C. The solid was filtered and added to a solution of NaI (20.6 g, 137.5 mmol) in acetone (515 ml, placed in a 1000 ml beaker) in small portions. After stirring the reaction mixture for 1.5 h at room temperature, an ice/water mixture (600 ml) was added to precipitate the product. The precipitate was filtered and dried in vacuo providing the title compound as a dark yellow solid (22.94 g, 72.3 mmol, 68%). HRMS calcd for $C_{10}H_8INO_3$: 316.9549; found 316.9553. 1H NMR (400 MHz, DMSO- d_6): δ 1.31 (t, $J = 7.1$, 3H), 4.33 (q, $J = 7.1$, 2H), 7.64 (s, 1H), 8.12 (s, 1H), 11.40 (s, 1H). ^{13}C NMR (100 MHz, DMSO- d_6): δ 13.82, 61.55, 106.64, 109.64, 115.90, 119.09, 128.18, 136.33, 161.59, 165.59.

2-Allyloxy-5-cyano-4-iodo-benzoic acid ethyl ester (10). To a solution of 5-cyano-2-hydroxy-4-iodo-benzoic acid ethyl ester (**9**) (20.8 g, 65.6 mmol) in DMF (320 ml) placed in a 500 ml flask was added Cs_2CO_3 (25.7 g, 78.7 mmol) and allyl bromide (6.8 ml, 78.7 mmol). The reaction mixture was stirred for 24 h at room temperature. The solvent was distilled and the residue was partitioned between water (275 ml) and toluene (250 ml). The aqueous phase was separated and extracted with toluene (5 x 300 ml). The organic layer was dried with $MgSO_4$ and evaporated. The resulting brown solid was re-crystallized from ethanol to yield the title compound as needles (17.9 g, 50.1 mmol, 76%). HRMS calcd for $C_{13}H_{12}INO_3$: 356.9862; found 356.9856. 1H NMR (400 MHz, DMSO- d_6): δ 1.31 (t, $J = 7.1$, 3H), 4.32 (q, $J = 7.1$, 2H), 4.85 (d, $J = 4.8$, 2H), 5.34 (dd, $J = 10.7$, $J = 1.4$, 1H), 5.51 (dd, $J = 17.2$, $J = 1.8$, 1H), 5.99-6.06 (m, 1H), 7.81 (s, 1H), 8.03 (s, 1H). ^{13}C NMR (100 MHz, DMSO- d_6): δ 13.89, 61.12, 69.40, 106.25, 110.87, 117.45, 119.06, 120.86, 124.44, 132.10, 135.94, 159.31, 163.59.

2-Allyloxy-5-cyano-4-iodo-benzoic acid (11). To a solution of 2-allyloxy-5-cyano-4-iodo-benzoic acid ethyl ester (**10**) (16.5 g, 45.3 mmol) in ethanol (250 ml) was added 10% aqueous NaOH (250 ml). After the resulting mixture was stirred for 1 h, the suspension was acidified to pH 1 by the addition of conc. HCl (about 80 ml). During addition, the mixture was cooled with ice. The resulting precipitate was filtered and dried to give the title compound as a white solid (14.9 g, 45.3 mmol, 100%). HRMS calcd for $C_{11}H_8INO_3$: 328.9549; found 328.9555. 1H NMR (400 MHz, DMSO- d_6): δ 4.83 (d, $J = 4.5$, 2H), 5.31 (dd, $J = 10.6$, $J = 1.4$, 1H), 5.52 (dd, $J = 17.2$, $J = 1.6$, 1H), 5.98-6.08 (m, 1H), 7.83 (s, 1H), 8.05 (s, 1H), 13.32 (bs, 1H). ^{13}C NMR (100 MHz, DMSO- d_6): δ 69.72, 106.35, 111.14, 117.93, 119.64, 122.52, 124.70, 132.64, 136.32, 159.75, 165.65.

Batch preparation of the iodobenzamide resin (13). Rink amide AM resin (5.0 g, 3.865 mmol, loading of 0.773 mmol/g) was Fmoc deprotected with 25% piperidine/DMF (100 ml) at room temperature for 1 h, filtered and washed successively with DMF, CH₂Cl₂, THF as well as CH₂Cl₂ and subsequently dried overnight in vacuo. To a slurry of the deprotected resin in DMF (100 ml) was added 2-allyloxy-5-cyano-4-iodo-benzoic acid (**11**) (5 equiv.), HOBt (5 equiv.) and DIC (5 equiv.), and the mixture was shaken at room temperature for 16 h. The resin was filtered and washed in the same way as above. Excess of solvent was removed in vacuo overnight to provide the derivatized resin **13** with a theoretical loading capacity of 0.723 mmol/g based on 100% conversion.

Library synthesis of biphenyl tetrazoles (18a-t). To resin **13** (100 mg, 0.072 mmol, loading of 0.723 mmol/g) suspended in DIEA/DMF (v/v = 1:1, 2 ml) was added boronic acid (10 equiv.) and Pd(PPh₃)₄ (0.2 equiv.) under an atmosphere of argon. The mixture was shaken at 100 °C for 22 h. After cooling to room temperature, the resin was filtered and washed with DMF, THF, acetone and CH₂Cl₂ (5 times each). To the dried resin was added a solution of PPh₃ (5 equiv.) in DMF (2 ml), alcohol (5 equiv.) and DIAD (5 equiv.), and the mixture was agitated at room temperature for 20 h. After filtration, the resin was charged again with a solution of PPh₃ (5 equiv.) in DMF (2 ml), alcohol (5 equiv.) and DIAD (5 equiv.), and agitated at room temperature for additional 20 h. The resin was filtered, washed with DMF, THF, methanol and CH₂Cl₂ and dried. Under an argon atmosphere, the resin was suspended in *o*-xylene (2 ml) and charged with *n*-Bu₂SnO (0.5 to 2 equiv.) and trimethylsilyl azide (5 to 10 equiv.). The mixture was agitated at 90 °C for 50 h. The filtered resin was washed with DMF, THF, methanol and CH₂Cl₂ and dried in vacuo. The resin was cleaved with 50% TFA/CH₂Cl₂ (2 ml) at room temperature for 1 h, filtered, and washed with CH₂Cl₂ (1 ml). The filtrate was evaporated to dryness and trace of the crude products was analyzed with LC/MS. Following purification by preparative HPLC, the products were characterized further by ¹H NMR. Initial purities and isolated yields of the products were shown in Table 1.

5-Isobutoxy-2-(1H-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18a). Initial LC/MS: 4.72 min, 74% (214 nm), *m/z* 338 [M+H⁺]. Isolated yield: 44%. ¹H NMR (400 MHz, CDCl₃): δ 1.12 (d, *J* = 6.6, 6H), 2.26 (nonet, *J* = 6.6, 1H), 4.03 (d, *J* = 6.6, 2H), 6.47 (bs, 1H), 7.07 (s, 1H), 7.24-7.25 (m, 2H), 7.37-7.41 (m, 3H), 8.13 (bs, 1H), 8.92 (s, 1H).

5-Isobutoxy-4'-methyl-2-(1H-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18b). Initial LC/MS: 5.07 min, 77% (214 nm), *m/z* 352 [M+H⁺]. Isolated yield: 25%. ¹H NMR (400 MHz, CDCl₃): δ 1.11 (d, *J* = 6.6, 6H), 2.25 (nonet, *J* = 6.6, 1H), 2.41 (s, 3H), 4.02 (d, *J* = 6.6, 2H), 6.37 (bs, 1H), 7.05 (s, 1H), 7.16 (d, *J* = 7.9, 2H), 7.23 (d, *J* = 7.9, 2H), 8.07 (bs, 1H), 8.95 (s, 1H).

4'-Chloro-5-isobutoxy-2-(1H-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18c). Initial LC/MS: 5.25 min, 70% (214 nm), *m/z* 372 [M+H⁺]. Isolated yield: 14%. ¹H NMR (400 MHz, CDCl₃): δ 1.13 (d, *J* = 6.6, 6H), 2.26 (nonet, *J* = 6.6, 1H), 4.04 (d, *J* = 6.7, 2H), 6.42 (bs, 1H), 7.04 (s, 1H), 7.22 (d, *J* = 8.4, 2H), 7.39 (d, *J* = 8.4, 2H), 8.14 (bs, 1H), 8.97 (s, 1H).

2'-Chloro-5-isobutoxy-2-(1H-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18d). Initial LC/MS: 5.01 min, 93% (214 nm), *m/z* 372 [M+H⁺]. Isolated yield: 36%. ¹H NMR (400 MHz, CDCl₃): δ 1.12 (d, *J* = 6.6, 3H), 1.13 (d, *J* = 6.6, 3H), 2.26 (nonet, *J* = 6.6, 1H), 4.04 (d, *J* = 6.6, 2H), 6.56 (bs, 1H), 7.05 (s, 1H), 7.34-7.45 (m, 4H), 8.27 (bs, 1H), 9.16 (s, 1H).

5-Isobutoxy-3'-methoxy-2-(1H-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18e). Initial LC/MS: 4.82 min, 76% (214 nm), *m/z* 368 [M+H⁺]. Isolated yield: 24%. ¹H NMR (400

MHz, CDCl₃): δ 1.11 (d, J = 6.6, 6H), 2.25 (nonet, J = 6.6, 1H), 3.78 (s, 3H), 4.02 (d, J = 6.6, 2H), 6.26 (bs, 1H), 6.79-6.83 (m, 2H), 6.96-6.98 (m, 1H), 7.05 (s, 1H), 7.32-7.36 (m, 1H), 7.99 (bs, 1H), 8.95 (s, 1H).

5-(2-Isopropoxyethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18f). Initial LC/MS: 4.40 min, 68% (214 nm), m/z 368 [M+H⁺]. Isolated yield: 29%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 1.21 (d, J = 6.0, 6H), 3.71 (sept, J = 6.0, 1H), 3.85-3.87 (m, 2H), 4.37-4.39 (m, 2H), 6.60 (bs, 1H), 7.12-7.34 (m, 6H), 8.02 (bs, 1H), 8.47 (s, 1H), 15.71 (bs, 1H).

5-(2-Isopropoxyethoxy)-4'-methyl-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18g). Initial LC/MS: 4.78 min, 66% (214 nm), m/z 382 [M+H⁺]. Isolated yield: 21%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 1.20 (d, J = 6.0, 6H), 2.35 (s, 3H), 3.71 (sept, J = 6.0, 1H), 3.85-3.87 (m, 2H), 4.36-4.38 (m, 2H), 6.68 (bs, 1H), 7.04-7.13 (m, 5H), 8.00 (bs, 1H), 8.43 (s, 1H), 15.71 (bs, 1H).

4'-Chloro-5-(2-isopropoxyethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18h). Initial LC/MS: 4.95 min, 65% (214 nm), m/z 402 [M+H⁺]. Isolated yield: 23%. ¹H NMR (400 MHz, CDCl₃): δ 1.21 (d, J = 6.1, 6H), 3.71 (sept, J = 6.1, 1H), 3.85-3.87 (m, 2H), 4.34-4.38 (m, 2H), 6.57 (bs, 1H), 7.05 (s, 1H), 7.13 (d, J = 8.4, 2H), 7.30 (d, J = 8.4, 2H), 8.01 (bs, 1H), 8.51 (s, 1H), 15.88 (bs, 1H).

2'-Chloro-5-(2-isopropoxyethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18i). Initial LC/MS: 4.71 min, 81% (214 nm), m/z 402 [M+H⁺]. Isolated yield: 27%. ¹H NMR (400 MHz, CDCl₃): δ 1.22 (d, J = 6.1, 6H), 3.72 (sept, J = 6.1, 1H), 3.86-3.88 (m, 2H), 4.37-4.39 (m, 2H), 6.43 (bs, 1H), 7.05 (s, 1H), 7.32-7.45 (m, 4H), 8.58 (bs, 1H), 9.14 (s, 1H).

5-(2-Isopropoxyethoxy)-3'-methoxy-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18j). Initial LC/MS: 4.52 min, 81% (214 nm), m/z 398 [M+H⁺]. Isolated yield: 30%. ¹H NMR (400 MHz, CDCl₃): δ 1.22 (d, J = 6.1, 6H), 3.71 (sept, J = 6.1, 1H), 3.74 (s, 3H), 3.85-3.87 (m, 2H), 4.35-4.37 (m, 2H), 6.25 (bs, 1H), 6.74-6.78 (m, 2H), 6.91-6.93 (m, 1H), 7.05 (s, 1H), 7.26-7.32 (m, 1H), 8.37 (bs, 1H), 8.83 (s, 1H).

5-(2-Phenylethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18k). Initial LC/MS: 5.03 min, 73% (214 nm), m/z 386 [M+H⁺]. Isolated yield: 36%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 3.23 (t, J = 6.5, 2H), 4.54 (t, J = 6.5, 2H), 7.14-7.34 (m, 8H), 7.40 (s, 1H), 8.29 (s, 1H), 15.99 (bs, 1H).

4'-Methyl-5-(2-phenylethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18l). Initial LC/MS: 5.34 min, 81% (214 nm), m/z 400 [M+H⁺]. Isolated yield: 42%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 2.34 (s, 3H), 3.23 (t, J = 6.6, 2H), 4.53 (t, J = 6.6, 2H), 7.04 (d, J = 8.0, 2H), 7.12 (d, J = 8.0, 2H), 7.16 (s, 1H), 7.22-7.28 (m, 1H), 7.33-7.35 (m, 5H), 7.41 (s, 1H), 8.26 (s, 1H), 15.90 (bs, 1H).

4'-Chloro-5-(2-phenylethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18m). Initial LC/MS: 5.51 min, 73% (214 nm), m/z 420 [M+H⁺]. Isolated yield: 41%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 3.24 (t, J = 6.6, 2H), 4.51 (t, J = 6.6, 2H), 7.01 (s, 1H), 7.10-7.14 (m, 3H), 7.24-7.37 (m, 8H), 8.42 (s, 1H).

2'-Chloro-5-(2-phenylethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18n). Initial LC/MS: 5.29 min, 84% (214 nm), m/z 420 [M+H⁺]. Isolated yield: 25%. ¹H NMR

(400 MHz, CDCl₃): δ 3.25 (t, J = 6.5, 2H), 4.53 (t, J = 6.5, 2H), 6.20 (bs, 1H), 7.05 (s, 1H), 7.26-7.44 (m, 9H), 7.74 (bs, 1H), 9.07 (s, 1H).

3'-Methoxy-5-(2-phenylethoxy)-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18o). Initial LC/MS: 5.11 min, 88% (214 nm), m/z 416 [M+H⁺]. Isolated yield: 27%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 3.24 (t, J = 6.6, 2H), 3.72 (s, 3H), 4.50 (t, J = 6.6, 2H), 6.30 (bs, 1H), 6.70-6.88 (m, 3H), 7.10 (s, 1H), 7.19-7.38 (m, 7H), 8.45 (s, 1H), 15.66 (bs, 1H).

5-Isopropoxy-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18p). Initial LC/MS: 4.20 min, 75% (214 nm), m/z 324 [M+H⁺]. Isolated yield: 39%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 1.49 (d, J = 6.0, 6H), 4.94 (sept, J = 6.0, 1H), 7.12-7.34 (m, 7H), 7.72 (s, 1H), 8.42 (s, 1H), 15.84 (bs, 1H).

5-Isopropoxy-4'-methyl-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18q). Initial LC/MS: 4.61 min, 75% (214 nm), m/z 338 [M+H⁺]. Isolated yield: 44%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 1.48 (d, J = 6.1, 6H), 2.35 (s, 3H), 4.95 (sept, J = 6.1, 1H), 7.03-7.14 (m, 5H), 7.49 (s, 1H), 7.67 (s, 1H), 8.34 (s, 1H), 15.88 (bs, 1H).

4'-Chloro-5-isopropoxy-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18r). Initial LC/MS: 4.78 min, 59% (214 nm), m/z 358 [M+H⁺]. Isolated yield: 24%. ¹H NMR (400 MHz, CDCl₃/DMSO-*d*₆): δ 1.48 (d, J = 6.0, 6H), 4.95 (sept, J = 6.0, 1H), 7.12-7.33 (m, 5H), 7.49 (s, 1H), 7.67 (s, 1H), 8.41 (s, 1H), 15.99 (bs, 1H).

2'-Chloro-5-isopropoxy-2-(1*H*-tetrazol-5-yl)-1,1'-biphenyl-4-carboxylic acid amide (18s). Initial LC/MS: 4.55 min, 91% (214 nm), m/z 358 [M+H⁺]. Isolated yield: 32%. ¹H NMR (400 MHz, CDCl₃): δ 1.52 (d, J = 6.1, 6H), 4.90 (sept, J = 6.1, 1H), 6.44 (s, 1H), 7.05-7.47 (m, 5H), 8.28 (s, 1H), 9.19 (s, 1H).

5-Isopropoxy-3'-methoxy-2-(1*H*-tetrazol-5-yl)-biphenyl-4-carboxylic acid amide (18t). Initial LC/MS: 4.35 min, 74% (214 nm), m/z 354 [M+H⁺]. Isolated yield: 18%.