HETEROCYCLES, Vol. 94, No. 7, 2017, pp. 1322 - 1336. © 2017 The Japan Institute of Heterocyclic Chemistry
Received, 14th April, 2017 , Accepted, 19th May, 2017, Published online, 9th June, 2017
DOI: 10.3987/COM-17-13723

TANDEM SONOGASHIRA-HAGIHARA COUPLING/CYCLO-ISOMERIZATION REACTIONS OF ETHYNYLBORONIC ACID MIDA ESTER TO AFFORD 2-HETEROCYCLIC BORONIC ACID MIDA ESTERS: A CONCISE ROUTE TO BENZOFURANS, INDOLES, FUROPYRIDINES AND PYRROLOPYRIDINES

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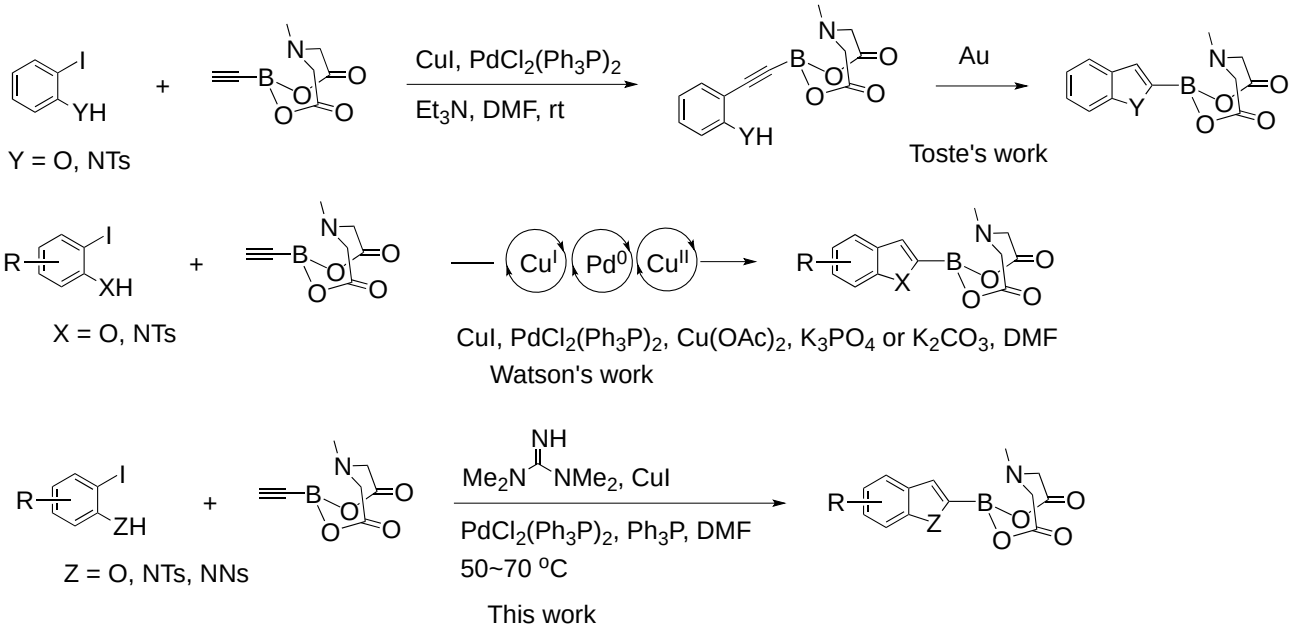
Abstract – A one-pot process that provides direct access to 2-heterocyclic MIDA (*N*-methyliminodiacetic acid) boronates has been developed. The reaction of 2-iodophenols or 2-iodoanilines with ethynylboronic acid MIDA ester readily afforded 2-substituted heterocyclic compounds. Amidine and phosphazene bases, especially TMG (1,1,3,3-tetramethylguanidine) assumed an important role in the tandem Sonogashira-Hagihara coupling/cycloisomerization reactions.

The palladium-catalyzed coupling reaction of organoboronic acids with organic halides, i.e., the Suzuki-Miyaura coupling, is one of the most efficient and reliable reactions in the synthesis of many natural products, pharmaceuticals and organic materials.[1] My research has focused on the development of a novel synthetic procedure for *N*-methyliminodiacetic acid (MIDA) boronates, which were developed by Burke *et al*., to synthesize benzofuran and indole derivatives.[2] Benzofuran and indole nucleus are ubiquitous framework found in many natural products and pharmaceuticals; therefore, the development of an efficient and versatile synthetic methodology to obtain these classes of compounds would be of great value.[3]

As a one of the new approach to aim the platform, tandem Sonogashira-Hagihara coupling[4]/ cycloisomerization reactions of ethynylboronic acid MIDA ester to afford 2-heterocyclic boronic acid MIDA esters were investigated. Although the Sonogashira-Hagihara reaction is a useful method to access heterocyclic compounds,[5] cross-coupling of halide with ethynylboronic acid MIDA ester has been limited. A two-step procedure (the Sonogashira-Hagihara coupling followed by the gold-catalyzed

cycloisomerization) has been described by Toste *et al*.[6] A prognosis that the modification of reaction conditions in the Sonogashira-Hagihara reaction might afford 2-heterocyclic boronic acid MIDA esters in a one-pot process led the investigation. Recently, Watson's group published a one-pot reaction of ethynylboronic acid MIDA ester to afford 2-heterocyclic boronic acid MIDA esters using Cu(I)/Pd(O)/Cu(II) catalysis and inorganic base.[7]



Scheme 1. Approaches towards 2-heterocyclic boronic acid MIDA esters

Herein I present an alternative one-pot synthesis of 2-heterocyclic boronic acid MIDA esters which provides efficient access to benzofurans, indoles, furopyridines and pyrrolopyridines. This reaction is using an amidine base and without Cu(II) salt, which fulfills a consequential role to led the ring closure in the Watson's report.

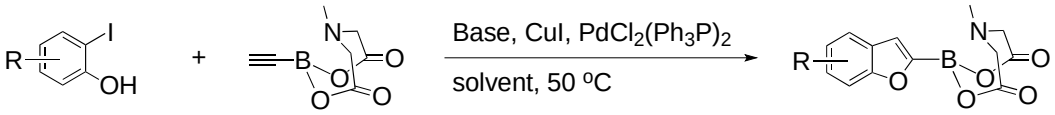
In the initial model experiment, as shown in Table 1, methyl 4-hydroxy-3-iodobenzoate (**1**) or 4-chloro-2-iodophenol (**2**) was treated with ethynylboronic acid MIDA ester in the presence of $PdCl_2(Ph_3P)_2$ and CuI. Table 1 summarizes the isolated yield of boronic acid MIDA ester under these reaction conditions. Although use of 1.6 equiv of Et_3N, a commonly used base in the Sonogashira-Hagihara reaction, afforded a small amount of coupling/cyclization product (**1A**) on LC-MS, **1A** was not isolated due to low conversion (entry 1a). Alternatively, replacement of Et_3N with 1,1,3,3-tetramethylguanidine (TMG), which has been effective in the tandem coupling/ cycloisomerization reaction of aliphatic or aromatic terminal alkynes in the solid-phase synthesis of indoles, was considered.[8] To my delight, **1A** and **2A** were obtained in 26% and 13% yield, respectively (entries 1b, 2a). Increasing the amount of TMG to 3.0 equiv impaired the reaction (entry 2b), while

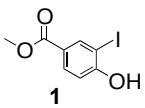
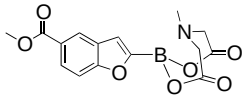
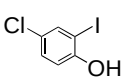
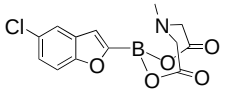
decreasing the amount of TMG to 1.2 equiv resulted in improved yield (entries 1d, 2c). A higher yield was observed in DMF compared to dioxane (entries 1c, 2g).

Next, the effect of additive was investigated to avoid consumption of terminal ethynyl compound during the reduction of Pd(II) to Pd(0). The addition of Ph_3P (0.1 equiv) increased the yield to 27% (entry 2d); however 0.3 equiv of Ph_3P complicated the reaction and made isolation of **2A** difficult (entry 2e). Although the effect of Ph_3P was limited, using a small excess of ethynylboronic acid MIDA ester enhanced the yield (entries 1e and 2h, based on **1** or **2**).

Under the optimized conditions, 1.3 equiv of ethynylboronic acid MIDA ester, 0.1 equiv of Ph_3P and 1.2 equiv of base in DMF, 2-*tert*-butylimino-2-dimethylamino-1,3-dimethylperhydro-1,3,2-diazaphosphorine (BEMP; a phosphazene base) or 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU; an amidine base) afforded **1A** in 34% and 64% yield, respectively (entries 1f and 1g). While the use of Et_3N afforded a small amount of the MIDA boronate on LC-MS, **1A** was not isolated due to low conversion (entry 1h). The uncyclized Sonogashira-Hagihara product intermediate was also detected on LC-MS, but was small in amount. The choice of base plays an important role in the tandem Sonogashira-Hagihara coupling/cycloisomerization reactions of ethynylboronic acid MIDA ester.

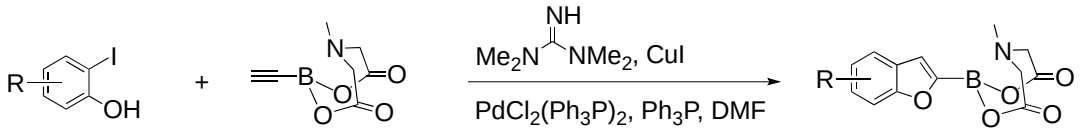
Table 1. Optimization of the reaction conditions for the synthesis of benzofuran-2-MIDA boronates[a]

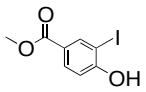
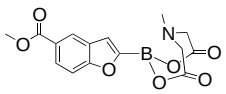
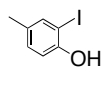
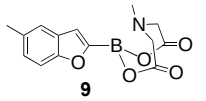
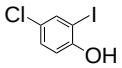
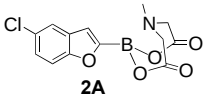
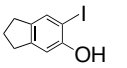
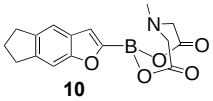
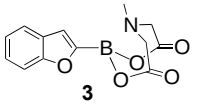
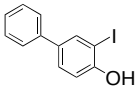
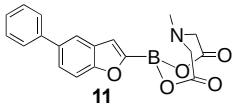
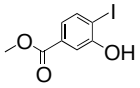
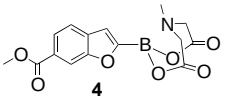
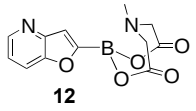
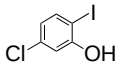
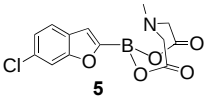
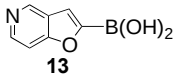
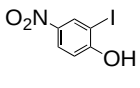
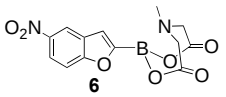
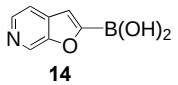
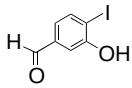
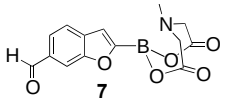
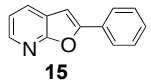
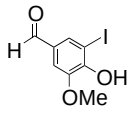
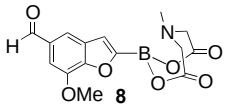
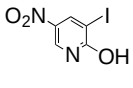
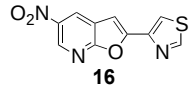


Entry	Substrate	MIDA ester (eq)	Base (eq)	Ph_3P (eq)	Solvent	Product	Yield[b] (%)
1a	 **1**	1.0	Et_3N (1.6)	-	DMF	 **1A**	-[c]
1b		1.0	TMG (1.6)	-	DMF		26
1c		1.0	TMG (1.6)	-	dioxane		15
1d		1.0	TMG (1.2)	0.1	DMF		45
1e		1.3	TMG (1.2)	0.1	DMF		75
1f		1.3	BEMP (1.2)	0.1	DMF		34
1g		1.3	DBU (1.2)	0.1	DMF		64
1h		1.3	Et_3N (1.2)	0.1	DMF		-[c]
2a	 **2**	1.0	TMG (1.6)	-	DMF	 **2A**	13
2b		1.0	TMG (3.0)	-	DMF		-[c]
2c		1.0	TMG (1.2)	-	DMF		44
2d		1.0	TMG (1.6)	0.1	DMF		27
2e		1.0	TMG (1.6)	0.3	DMF		-[c]
2f		1.0	TMG (1.2)	0.1	DMF		52
2g		1.0	TMG (1.2)	0.1	dioxane		40
2h		1.3	TMG (1.2)	0.1	DMF		87

[a] Reaction conditions: 2.0 mmol of **1** or **2**, 10 mol% of CuI, 5 mol% of $PdCl_2(Ph_3P)_2$, 6.0 mL solvent, 50 °C, N_2 atmosphere, 22 h. [b] Isolated yields. [c] Not isolated due to low conversion.

Table 2. The reaction of 2-iodophenols and ethynylboronic acid MIDA ester[a]



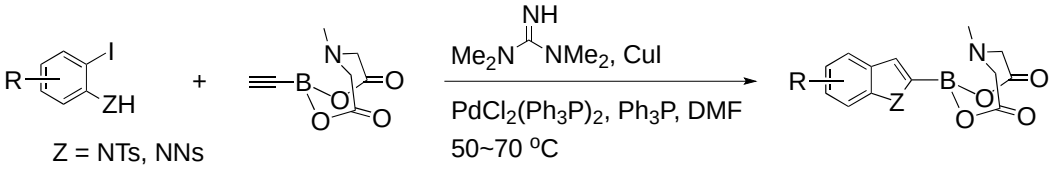
Entry	ArI	Yield[b] (%)	Product	Entry	ArI	Yield[b] (%)	Product
1		75	 **1A**	9		20 42[c]	 **9**
2		87	 **2A**	10		12 25[c]	 **10**
3		60	 **3**	11		70[c]	 **11**
4		73	 **4**	12		45 43[c]	 **12**
5		47	 **5**	13		41[d]	 **13**
6		68	 **6**	14		60[d]	 **14**
7		36	 **7**	15		34[c,e]	 **15**
8		26[c]	 **8**	16		7[c,e]	 **16**

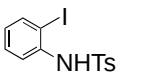
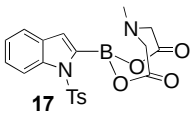
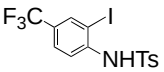
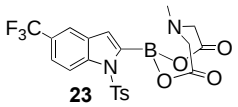
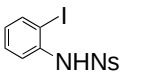
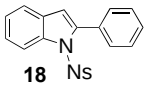
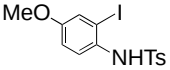
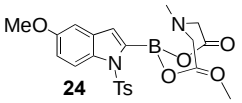
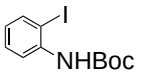
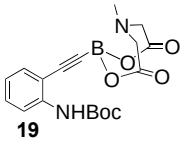
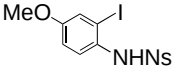
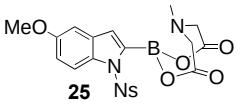
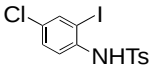
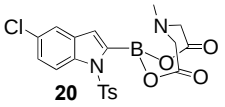
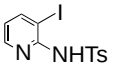
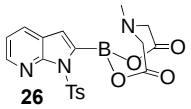
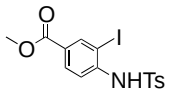
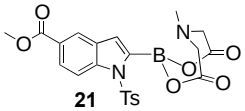
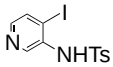
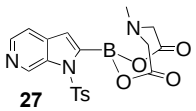
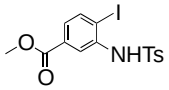
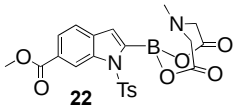
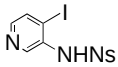
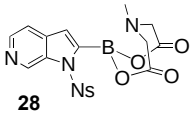
[a] General reaction conditions: 1 equiv of aryl iodide (2.0 mmol), 1.3 equiv of ethynylboronic acid MIDA ester, 10 mol% of CuI, 5 mol% of $PdCl_2(Ph_3P)_2$, 10 mol% of Ph_3P, 1.2 equiv of TMG, 6.0 mL DMF, 50 °C, 22 h. [b] Isolated yields. [c] Reaction conducted at 70 °C. [d] 1 : 1 mixture of the MIDA boronate and boronic acid was obtained. The mixture was converted to the boronic acid by treatment with EtOH. [e] As MIDA boronate was difficult to isolate, yield was determined by the following arylation reaction of crude MIDA boronate.

The optimized conditions were applied to a variety of phenols and pyridinols to examine the versatility of this methodology. As demonstrated in Table 2, substrates bearing different functional groups were tolerant of the reaction conditions and provided the corresponding products with moderate to high isolated yields. When the uncyclized Sonogashira-Hagihara product intermediate remained at 50 °C, the reaction was conducted at 70 °C. The temperature range between 50 °C and 70 °C was determined to be suitable for this reaction, as higher reaction temperatures often caused reduction in yield. While 2-iodopyridin-3-ol cleanly afforded the corresponding MIDA boronate in 45% yield (entry 12),

3-iodopyridin-4-ol and 4-iodopyridinol afforded 1 : 1 mixtures of the MIDA boronate and boronic acid after column chromatography (eluent, CH_2Cl_2 : MeOH = 10 : 1). The mixtures were converted to the boronic acid by treatment with EtOH (entries 13 and 14). The MIDA boronate and boronic acid prepared from 3-iodopyridin-2-ol were difficult to isolate; therefor the crude MIDA boronate were converged to 2-aryl derivatives by Lipshutz's method (entries 15 and 16).[9]

Table 3. The reaction of 2-iodoanilines and ethynylboronic acid MIDA ester[a]



Entry	ArI	Yield[b] (%)	Product	Entry	ArI	Yield[b] (%)	Product
1		81	 **17**	7		50	 **23**
2		15[c]	 **18**	8		45	 **24**
3		70[d]	 **19**	9		18 40[d]	 **25**
4		69	 **20**	10		16 18[e] 56[d]	 **26**
5		61	 **21**	11		46	 **27**
6		85	 **22**	12		15[d]	 **28**

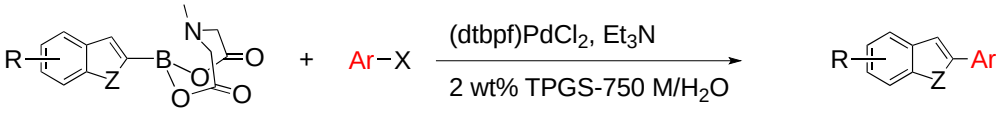
[a] General reaction conditions: 1 equiv of aryl iodide (2.0 mmol), 1.3 equiv of ethynylboronic acid MIDA ester, 10 mol% of CuI, 5 mol% of $(Ph_3P)_2PdCl_2$, 10 mol% of Ph_3P, 1.2 equiv of TMG, 6.0 mL DMF, 50 °C, 22 h. [b] Isolated yields. [c] As MIDA boronate was difficult to isolate, yield was determined by the following arylation reaction of crude MIDA boronate. [d] Reaction conducted at 70 °C. [e] Using 1.6 equiv of ethynylboronic acid MIDA ester.

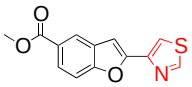
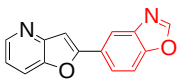
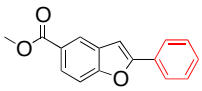
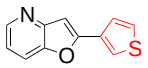
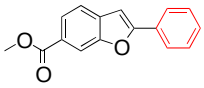
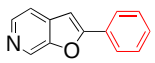
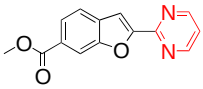
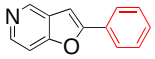
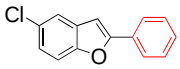
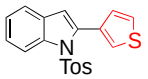
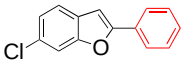
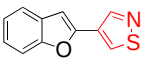
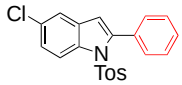
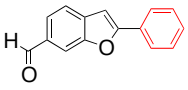
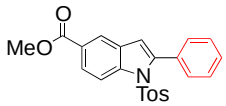
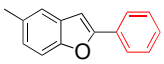
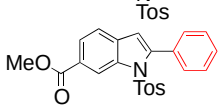
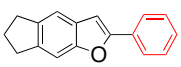
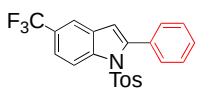
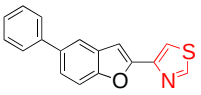
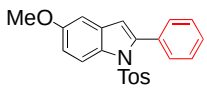
The reaction was also found to be effective in anilines, as shown in Table 3. The protecting group of 2-iodoaniline was screened. Although tosylated and nosylated anilines afforded corresponding indole-2-MIDA boronate, *N*-Boc derivative did not provide the indole product; the uncyclized alkyne was obtained even after heating at 70 °C (Table 3, entries 1~3). Isolation of *N*-nosylated indole-2-boronic acid MIDA ester by chromatography or recrystallization was problematic; therefore the crude MIDA boronate

was used in the subsequent arylation.[9] 2-Iodoanilines afforded cyclized MIDA boronates as well as 2-iodophenols via tandem Sonogashira-Hagihara coupling/cycloisomerization reactions of ethynyl-boronic acid MIDA ester.

The obtained MIDA boronates were examined to determine if these serve as the intermediate in the synthesis of 2-substituted heterocyclic compounds.[10] The preliminary results of Suzuki-Miyaura coupling reaction are summarized in Table 4. In the case of *N*-nosylindole derivatives, a significant amount of the reduced product at 2-position were obtained in addition to the coupled product (Table 4, entry 26).

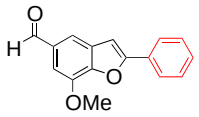
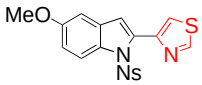
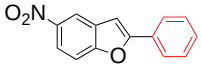
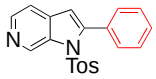
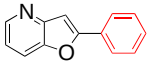
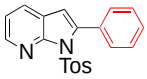
Table 4. Suzuki-Miyaura coupling reactions of MIDA boronates in Lipshutz's conditions[a]



Entry	Product	X (Yield%)[b]	Entry	Product	X (Yield%)[b]
1		Br (72)	15		Br (72)
2		Br (86)[c] Br (94)	16		Br (63)
3		Br (76)	17		Br (41)[d]
4		Cl (28)	18		Br (43)[d]
5		Br (96) I (66)	19		Br (80)
6		Br (85)	20		Br (82)
7		Br (87)	21		Br (92)
8		Br (94)	22		Br (30)
9		Br (71)	23		Br (63)
10		Br (44)	24		Br (68)
11		Br (50)	25		Br (45)

continued

continued

12		Br (77)	26		Br (33)[e]
13		Br (87)	27		Br (46)
14		Br (74)	28		Br (32)

[a] General reaction conditions: 1 equiv of MIDA boronate (0.60 mmol), 1 equiv of aryl halide, 8 mol% of (dtbpf)$PdCl_2$, 1.5 mL of 2 wt% TPGS-750M H_2O, 3 equiv of Et_3N, 40 °C, 22 h. [b] Isolated yields. [c] Reaction conducted at room temperature. [d] Corresponding boronic acid was used. [e] 57% of 5-methoxy-*N*-Ns-indole was obtained.

EXPERIMENTAL

General. All reagents and anhydrous solvents were purchased from commercial suppliers and used without further purification. All reactions were performed under a nitrogen atmosphere. Automated flash chromatography was performed on YAMAZEN UV-10VW with peak detection at 254 nm. ^{1}H (400 MHz) NMR spectra were recorded on a Bruker Avance^{III} 400. For ^{1}H-NMR spectroscopy, tetramethylsilane (δ = 0 ppm) in served as an internal standard. High-resolution MS data were obtained on a Thermo Scientific LTQ Orbitrap XL. High-resolution MS spectral analysis was performed on a Xcalibur. Melting points were uncorrected. IR spectra were recorded on a HORIBA FT-720.

Typical procedure for the synthesis of 2-benzofuranboronic acid MIDA esters. 5-Methoxycarbonylbenzofuran-2-MIDA boronate (1A). Dry DMF (6.0 mL) was added to methyl 4-hydroxy-3-iodobenzoate (0.56 g, 2.0 mmol), ethynylboronic acid MIDA ester (0.47 g, 2.6 mmol), CuI (38 mg, 0.20 mmol), $PdCl_2(Ph_3P)_2$ (70 mg, 0.10 mmol) and Ph_3P (52 mg, 0.20 mmol) under N_2. 1,1,3,3-Tetramethylguanidine (TMG) (0.30 mL, 2.4 mmol) was added to the resulting solution under N_2. The reaction mixture was stirred at 50 °C for 22 h under N_2. The resulting mixture was diluted with water to form a precipitate, which was filtered, washed with water and dried at room temperature. The obtained solid was dissolved in acetone and purified by flash chromatography (SiO_2, CH_2Cl_2 : MeOH = 10 : 1). The eluted material was washed with hot EtOH and dried to give **1A** (493.6 mg, 75%) as a pale brown solid; mp 209-212 °C (Dec.); IR (cm^{-1}) 1749, 1712, 1558, 1508, 1437, 1352, 1292, 1232, 1188, 1138, 1089, 1038; ^{1}H-NMR (DMSO-d_6) δ 2.72 (s, 3H), 3.87 (s, 3H), 4.20 (d, *J* = 17.0 Hz, 2H), 4.44 (d, *J* = 17.0 Hz, 2H), 7.24 (d, *J* = 1.0 Hz, 1H), 7.69 (d, *J* = 8.5 Hz, 1H), 7.93 (dd, *J* = 1.5 Hz, 8.5 Hz, 1H), 8.34 (d, *J* = 1.5 Hz, 1H); Anal. Calcd for $C_{15}H_{14}NO_7B$•1/4H_2O (C, H, N) (53.68, 4.35, 4.17). Found (53.42, 4.03, 4.20); HRMS calcd for $C_{15}H_{15}NO_7N$ [M+H] 332.0936, found 332.0936 (Δ 0.04).

5-Chlorobenzofuran-2-MIDA boronate (2A): Prepared from 4-chloro-2-iodophenol and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **2A** (533.5 mg, 87%) as a pale yellow solid; mp 214-218 °C (Dec.); IR (cm^{-1}) 1749, 1558, 1446, 1363, 1282, 1228, 1138, 1092,

1045, 1001; ^{1}H-NMR (DMSO-d_6) δ 2.70 (s, 3H), 4.19 (d, *J* = 17.0 Hz, 2H), 4.43 (d, *J* = 17.0 Hz, 2H), 7.08 (brs, 1H), 7.32 (dd, *J* = 2.0 Hz, 8.5 Hz, 1H), 7.61 (d, *J* = 8.5 Hz, 1H), 7.74 (d, *J* = 2.0 Hz, 1H); Anal. Calcd for $C_{13}H_{11}NO_5BCl$•1/4H_2O (C, H, N) (50.05, 3.71, 4.48). Found (50.26, 3.80, 4.40); HRMS calcd for $C_{13}H_{11}NO_5BCl$ [M] 307.0413, found 307.0416 (Δ 0.32).

Benzofuran-2-MIDA boronate (3): Prepared from methyl 4-hydroxy-3-iodobenzoate and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **3** (327.4 mg, 60%) as a pale yellow solid; IR (cm^{-1}) 1749, 1558, 1515, 1456, 1373, 1338, 1232, 1138, 1047; ^{1}H-NMR (DMSO-d_6) δ 2.69 (s, 3H), 4.18 (d, *J* = 17.0 Hz, 2H), 4.42 (d, *J* = 17.0 Hz, 2H), 7.08 (d, *J* = 1.0 Hz, 1H), 7.20-7.25 (m, 1H), 7.27-7.32 (m, 1H), 7.55-7.59 (m, 1H), 7.63-7.67 (m, 1H); HRMS calcd for $C_{13}H_{13}NO_5B$ [M+H] 274.0881, found 274.0879 (Δ 0.21).

6-Methoxycarbonylbenzofuran-2-MIDA boronate (4): Prepared from 3-hydroxy-4-iodobenzoate and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and washing with hot EtOH afforded **4** (481.8 mg, 73%) as a pale brown solid; mp 270-273 °C (Dec.); IR (cm^{-1}) 1749, 1707, 1431, 1346, 1298, 1217, 1149, 1053; ^{1}H-NMR (DMSO-d_6) δ 2.71 (s, 3H), 3.88 (s, 3H), 4.20 (d, *J* = 17.0 Hz, 2H), 4.44 (d, *J* = 17.0 Hz, 2H), 7.20 (d, *J* = 1.0 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.86 (dd, *J* = 1.5 Hz, 8.0 Hz, 1H), 8.34 (d, *J* = 1.5 Hz, 1H); Anal. Calcd for $C_{15}H_{14}NO_7B$•1/4H_2O (C, H, N) (53.68, 4.35, 4.17). Found (53.42, 4.10, 4.26); HRMS calcd for $C_{15}H_{15}NO_7B$ [M+H] 332.0936, found 332.0938 (Δ 0.23).

6-Chlorobenzofuran-2-MIDA boronate (5): Prepared from 5-chloro-2-iodophenol and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and washing with hot EtOH afforded **5** (290.3 mg, 47%) as a pale brown solid; mp 189-191 °C (Dec.); IR (cm^{-1}) 1749, 1558, 1458, 1373, 1261, 1217, 1146, 1055; ^{1}H-NMR (DMSO-d_6) δ 2.69 (s, 3H), 4.18 (d, *J* = 17.0 Hz, 2H), 4.43 (d, *J* = 17.0 Hz, 2H), 7.11 (d, *J* = 1.0 Hz, 1H), 7.28 (dd, *J* = 2.0 Hz, 8.5 Hz, 1H), 7.67 (d, *J* = 8.5 Hz, 1H), 7.22-7.74 (m, 1H); Anal. Calcd for $C_{13}H_{11}NO_5BCl$•1/8H_2O (C, H, N) (50.41, 3.66, 4.52). Found (50.17, 3.41, 4.66); HRMS calcd for $C_{13}H_{11}NO_5BCl$ [M] 307.0413, found 307.0413 (Δ 0.04).

5-Nitrobenzofuran-2-MIDA boronate (6): Prepared from 2-iodo-4-nitrophenol and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **6** (434.9 mg, 68%) as a pale yellow solid; mp 232-236 °C (Dec.); IR (cm^{-1}) 2376, 2310, 1743, 1522, 1458, 1348, 1277, 1230, 1144, 1047, 1001; ^{1}H-NMR (DMSO-d_6) δ 2.73 (s, 3H), 4.22 (d, *J* = 17.0 Hz, 2H), 4.46 (d, *J* = 17.0 Hz, 2H), 7.33 (d, *J* = 0.5 Hz, 1H), 7.82 (d, *J* = 9.0 Hz, 1H), 8.21(dd, *J* = 2.5 Hz, 9.0 Hz, 1H), 8.66 (d, *J* = 2.5 Hz, 1H); Anal. Calcd for $C_{13}H_{11}N_2O_7B$ (C, H, N) (49.09, 3.49, 8.81). Found (48.99, 3.37, 8.53); HRMS calcd for $C_{13}H_{11}N_2O_7B$ [M] 318.0654, found 318.0648 (Δ 0.59).

6-Carbaldehydebenzofuran-2-MIDA boronate (7): Prepared from 3-hydroxy-4-iodobenzaldehyde and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and washing with hot EtOH afforded **7** (214.9 mg, 36%) as a pale brown solid; mp 192-196 °C (Dec.); IR (cm^{-1}) 1757, 1682,

1610, 1558, 1458, 1273, 1225, 1196, 1142, 105; ^{1}H-NMR (DMSO-d_6) δ 2.72 (s, 3H), 4.21 (d, J = 17.0 Hz, 2H), 4.45 (d, J = 17.0 Hz, 2H), 7.24 (d, J = 1.0 Hz, 1H), 7.80 (dd, J = 1.0 Hz, 8.0 Hz, 1H), 7.86 (d, J = 8.0 Hz, 1H), 8.12 (brs, 1H), 10.07 (s, 1H); Anal. Calcd for $C_{14}H_{12}NO_6B$ (C, H, N) (55.85, 4.02, 4.65). Found (55.67, 4.11, 4.37); HRMS calcd for $C_{14}H_{12}NO_6B$ [M] 301.0752, found 301.0751 (Δ 0.15).

5-Carbaldehyde-7-methoxy-benzofuran-2-MIDA boronate (8): Prepared from 5-iodovanillin and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and washing with hot EtOH afforded **8** (174.1 mg, 26%) as a pale brown solid; mp 229-231 °C (Dec.); IR (cm^{-1}) 1755, 1689, 1597, 1464, 1335, 1296, 1232, 1144, 1049, 1009; ^{1}H-NMR (DMSO-d_6) δ 2.72 (s, 3H), 4.01 (s, 3H), 4.20 (d, J = 17.5 Hz, 2H), 4.44 (d, J = 17.5 Hz, 2H), 7.27 (s, 1H), 7.38 (d, J = 1.5 Hz, 1H), 7.91 (d, J = 1.5 Hz, 1H), 10.01 (s, 1H); Anal. Calcd for $C_{15}H_{14}NO_7B$ (C, H, N) (54.42, 4.26, 4.23). Found (54.29, 4.08, 4.17); HRMS calcd for $C_{13}H_{15}NO_7B$ [M+H] 332.0936, found 332.0935 (Δ 0.12).

5-Methylbenzofuran-2-MIDA boronate (9): Prepared from 2-iodo-4-methylbenzoate and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt : hexane = 1 : 1) and washing with hot EtOH afforded **9** (242.4 mg, 42%) as a pale brown solid; mp 200-204 °C (Dec.); IR (cm^{-1}) 1747, 1566, 1456, 1336, 1284, 1228, 1167, 1120, 1041; ^{1}H-NMR (DMSO-d_6) δ 2.38 (s, 3H), 2.67 (s, 3H), 4.17 (d, J = 17.0 Hz, 2H), 4.41 (d, J = 17.0 Hz, 2H), 6.99 (d, J = 1.0 Hz, 1H), 7.10 (dd, J = 1.5 Hz, 8.5 Hz, 1H), 7.40-7.46 (m, 2H); Anal. Calcd for $C_{14}H_{14}NO_5B$•1/4H_2O (C, H, N) (57.67, 5.01, 4.80). Found (57.46, 4.94, 4.85); HRMS calcd for $C_{14}H_{14}NO_5B$ [M] 287.0960, found 287.0955 (Δ 0.56).

6,7-Dihydro-5*H*-indeno[5,6-*b*]furan-2-MIDA boronate (10): Prepared from 6-iodo-5-hydroxyindane and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and washing with hot EtOH afforded **10** (154.6 mg, 25%) as a pale yellow solid; mp 217-220 °C (Dec.); IR (cm^{-1}) 1743, 1558, 1516, 1458, 1417, 1373, 1338, 1288, 1232, 1146, 1036; ^{1}H-NMR (DMSO-d_6) δ 2.01-2.10 (m, 2H), 2.66 (s, 3H), 2.85-2.95 (m, 4H), 4.16 (d, J = 17.0 Hz, 2H), 4.40 (d, J = 17.0 Hz, 2H), 6.96 (d, J = 0.5 Hz, 1H), 7.38 (s, 1H), 7.41 (s, 1H); HRMS calcd for $C_{16}H_{16}NO_5$ [M] 313.1116, found 313.112 (Δ 0.43).

5-Phenylbenzofuran-2-MIDA boronate (11): Prepared from 4-chloro-2-iodophenol and ethynylboronic acid MIDA ester. Purification by flash chromatography (CH_2Cl_2 : MeOH = 10 : 1) afforded **11** (487.7 mg, 70%) as a pale brown solid; mp 195-200 °C (Dec.); IR (cm^{-1}) 1745, 1571, 1450, 1336, 1281, 1232, 1176, 1138, 1041; ^{1}H-NMR (DMSO-d_6) δ 2.72 (s, 3H), 4.20 (d, J = 17.0 Hz, 2H), 4.44 (d, J = 17.0 Hz, 2H), 7.13 (d, J = 1.0 Hz, 1H), 7.32-7.38 (m, 1H), 7.43-7.50 (m, 2H), 7.58 (dd, J = 2.0 Hz, 8.5 Hz, 1H), 7.63-7.71 (m, 3H), 7.91 (d, J = 1.5 Hz, 1H); Anal. Calcd for $C_{19}H_{16}NO_5B$•1/2H_2O (C, H, N) (63.72, 4.78, 3.91). Found (63.88, 4.34, 3.53); HRMS calcd for $C_{19}H_{16}NO_5B$ [M] 349.1116, found 349.1114 (Δ 0.25).

Furo[2,2-*b*]pyridine-2-MIDA boronate (12): Prepared from 3-hydroxy-2-iodopyridine and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **12** (248.4 mg, 45%) as a pale yellow solid; mp 216-220 °C (Dec.); IR (cm^{-1}) 3178, 1739, 1646, 1558, 1516, 1456, 1417, 1373,

1338, 1279, 1216, 1049, 1005; ^{1}H-NMR (DMSO-d_6) δ 2.72 (s, 3H), 4.21 (d, J = 17.0 Hz, 2H), 4.45 (d, J = 17.0 Hz, 2H), 7.21 (d, J = 1.0 Hz, 1H), 7.33 (dd, J = 4.5 Hz, 8.5 Hz, 1H), 7.98-8.04 (m, 1H), 8.51 (brd, J = 4.0 Hz, 1H); Anal. Calcd for $C_{12}H_{11}N_2O_5B$•1/4H_2O (C, H, N) (51.74, 4.16, 10.06). Found (51.98, 4.13, 9.58); HRMS calcd for $C_{12}H_{12}N_2O_5B$ [M+H] 275.0834, found 275.0836 (Δ 0.24).

Furo[3,2-*c*]-2-boronic acid (13): Prepared from 4-hydroxy-3-iodopyridine and ethynylboronic acid MIDA ester. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, CH_2Cl_2 : MeOH = 10 : 1) to give 180.7 mg of 1 : 1 mixture of MIDA boronate and boronic acid as a pale yellow powder (41%). The mixture was treated with hot EtOH to afford **13** (109.9 mg, 34%) as a pale yellow solid; IR (cm^{-1}) 3000, 1736, 1616, 1591, 1570, 1541, 1473, 1373, 1356, 1300, 1228, 1164, 1145, 1039; ^{1}H-NMR (DMSO-d_6) δ 7.57 (d, J = 0.5 Hz, 1H), 7.65 (d, J = 6.0 Hz, 1H), 8.46 (d, J = 6.0 Hz, 1H), 9.00 (s, 1H); HRMS calcd for $C_7H_7NO_3B$ [M+H] 164.0514, found 164.0513 (Δ 0.05).

Furo[2,3-*c*]-2-boronic acid (14): Prepared from 3-hydroxy-4-iodopyridine and ethynylboronic acid MIDA ester. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, CH_2Cl_2 : MeOH = 10 : 1) to give 262.4 mg of 1 : 1 mixture of MIDA boronate and boronic acid as a pale yellow powder. The mixture was treated with hot EtOH to afford **14** (216.4 mg, 66%) as a pale yellow solid; IR (cm^{-1}) 3006, 1734, 1683, 1608, 1473, 1373, 1322, 1259, 1216, 1159, 1093, 1016; ^{1}H-NMR (DMSO-d_6) δ 7.50 (d, J = 1.0 Hz, 1H), 7.74 (dd, J = 1.0 Hz, 5.0 Hz, 1H), 8.37 (d, J = 5.0 Hz, 1H), 8.96 (brs, 1H); HRMS calcd for $C_7H_7NO_3B$ [M+H] 164.0514, found 164.0514 (Δ 0.07).

2-Phenylfuro[2,3-*b*]pyridine (15) via furo[2,3-*b*]pyridine-2-MIDA boronate: Prepared from 2-hydroxy-3-iodopyridine and ethynylboronic acid MIDA ester. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt) to give 386.0 mg of a pale yellow amorphous solid. The crude product was used in the next reaction without further purification since the product was unstable to EtOH treatment. ^{1}H-NMR (crude, DMSO-d_6) δ 2.73 (s, 3H), 4.21 (d, J = 17.0 Hz, 2H), 4.44 (d, J = 17.0 Hz, 2H), 7.14 (s, 1H), 7.33 (dd, J = 5.0 Hz, 7.5 Hz, 1H), 8.12 (dd, J = 1.5 Hz, 7.5 Hz, 1H), 8.30 (dd, J = 1.5 Hz, 5.0 Hz, 1H).

2 wt% DL-α-Tocopherolmethoxypolyeneglycol succinate solution (3.5 mL) was added to a mixture of the crude furo[2,3-*b*]pyridine-2-MIDA boronate and bromobenzene (221 mg) under N_2. Et_3N (0.52 mL) was added to the suspension under N_2. The reaction mixture was vigorously stirred at 40 °C for 22 h under N_2. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt : hexane = 30 : 70) to give **15** (132.6 mg, 34%, 2 steps) as a yellow solid; mp 90-91 °C (hexane, yellow prisms); IR

(cm^{-1}) 1739, 1597, 1562, 1491, 1471, 1446, 1402, 1244, 1173, 1113, 1020; ^{1}H-NMR ($CDCl_3$) δ 7.01 (s, 1H), 7.23 (dd, *J* = 5.0 Hz, 7.5 Hz, 1H), 7.37-7.42 (m, 1H), 7.44-7.50 (m, 2H), 7.88-7.94 (m, 3H), 8.30 (dd, *J* = 1.5 Hz, 5.0 Hz, 1H); Anal. Calcd for $C_{13}H_9NO$ (C, H, N) (79.98, 4.65, 7.17). Found (80.50, 4.48, 7.23); HRMS calcd for $C_{13}H_{10}NO$ [M+H] 196.0757, found 196.0757 (Δ 0.07).

5-Nitro-2-(thiazol-4-yl)furo[2,3-*b*]pyridine (16) via 5-nitrofuro[2,3-*b*]pyridine-2-2-MIDA boronate: Prepared from 2-hydroxy-3-iodo-5-nitropyridine and ethynylboronic acid MIDA ester. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt) to give 212.7 mg of a pale brown amorphous solid. The crude product was used in the next reaction without further purification. 2 wt% DL-α-Tocopherolmethoxypolyeneglycol succinate solution (3.5 mL) was added to a mixture of the crude furo[2,3-*b*]pyridine-2-MIDA boronate, (dtbpf)$PdCl_2$ (104 mg) and 4-bromothiazole (0.33 g) under N_2. Et_3N (0.61 mL) was added to the suspension under N_2. The reaction mixture was vigorously stirred at 40 °C for 22 h under N_2. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt : hexane = 30 : 70) to give **16** (34.5 mg, 7%, 2 steps) as a yellow solid; mp 273-276 °C (Dec., AcOEt-hexane, yellow powder); IR (cm^{-1}) 1738, 1604, 1508, 1471, 1348, 1265, 1155, 1076, 1041; ^{1}H-NMR ($CDCl_3$) δ 7.37 (s, 1H), 8.01 (d, *J* = 2.0 Hz, 1H), 8.79 (d, *J* = 2.5 Hz, 1H), 8.95 (d, *J* = 2.0 Hz, 1H), 9.24 (d, *J* = 2.5 Hz, 1H); HRMS calcd for $C_{10}H_6N_3O_3S$ [M+H] 248.0124, found 248.0122 (Δ 0.23).

1-Ts-1*H*-indole-2-MIDA boronate (17): Prepared from 2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **17** (693.2 mg, 81%) as a pale yellow solid; IR (cm^{-1}) 1747, 1446, 1362, 1300, 1228, 1173, 1090, 1036, 1011; ^{1}H-NMR (DMSO-d_6) δ 2.32 (s, 3H), 2.96 (s, 3H), 4.23 (d, *J* = 17.5 Hz, 2H), 4.47 (d, *J* = 17.5 Hz, 2H), 7.06 (d, *J* = 0.5 Hz, 1H), 7.22-7.28 (m, 1H), 7.33-7.41 (m, 3H), 7.63 (brd, *J* = 7.5 Hz, 1H), 7.91 (brd, *J* = 8.5 Hz, 2H), 8.10-8.13 (m, 1H); HRMS calcd for $C_{20}H_{20}N_2O_6BS$ [M+H] 427.1130, found 427.1130 (Δ 0.01).

2-Phenyl-1-Ns-1*H*-indole (18) via 1-Ns-1*H*-indole-2-MIDA boronate: Prepared from 2-iodo-1-Ns-aniline and ethynylboronic acid MIDA ester. The resulting mixture was diluted with water to form a precipitate, which was filtered, washed with water and dried at room temperature. The obtained solid was dissolved in acetone and purified by flash chromatography (SiO_2, AcOEt). The eluted material was washed with hot EtOH and dried to give 572.4 mg of crude MIDA boronate as a pale brown solid. The crude product was used in the next reaction without further purification. 2 wt% DL-α-Tocopherol-methoxypolyeneglycol succinate solution (3.5 mL) was added to a mixture of the crude furo-[2,3-*b*]pyridine-2-MIDA boronate, (dtbpf)$PdCl_2$ (104 mg) and 4-bromothiazole (0.33 g) under N_2. Et_3N (0.61 mL) was added to the suspension under N_2. The reaction mixture was vigorously stirred at 40 °C for

22 h under N_2. The resulting mixture was diluted with water and extracted with AcOEt. The organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt : hexane = 30 : 70) to give **18** (246.7 mg, 15%, 2 steps) as a pale yellow solid; mp 100-102 °C (hexane, pale yellow powder); IR (cm^{-1}) 1739, 1541, 1448, 1362, 1215, 1174, 1119, 1059; ^{1}H-NMR ($CDCl_3$) δ 6.64 (d, *J* = 0.5 Hz, 1H), 7.09 (dd, *J* = 1.0 Hz, 8.0 Hz, 1H), 7.26-7.40 (m, 8H), 7.55-7.64 (m, 3H), 8.06-8.10 (m, 1H); Anal. Calcd for $C_{20}H_{14}N_2O_4S$ (C, H, N) (63.48, 3.78, 7.40). Found (63.35, 3.93, 7.28); HRMS calcd for $C_{20}H_{15}N_2O_4S$ [M+H] 379.0747, found 379.0749 (Δ 0.25).

***N*-Boc-2-(ethynylboronic acid MIDA ester)aniline (19):** Prepared from 2-iodo-*N*-Boc-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **19** (521.9 mg, 70%) as a pale yellow powder; mp 77-79 °C (hexane, pale yellow powder); IR (cm^{-1}) 1766, 1734, 1577, 1516, 1446, 1367, 1230, 1149, 1117, 1065, 1020; ^{1}H-NMR (DMSO-d_6) δ 1.45 (s, 9H), 3.13 (s, 3H), 4.14 (d, *J* = 17.0 Hz, 2H), 4.33 (d, *J* = 17.0 Hz, 2H), 7.06-7.11 (m, 1H), 7.33-7.39 (m, 1H), 7.46 (dd, *J* = 1.5 Hz, 8.0 Hz, 1H), 7.66 (d, *J* = 8.0 Hz, 1H), 8.25 (s, 1H); $C_{18}H_{21}N_2O_6BNa$ [M+Na] 395.13947, found 395.14924 (Δ 0.97).

5-Chloro-1-Ts-1*H*-indole-2-MIDA boronate (20): Prepared from 4-chloro-2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **20** (637.9 mg, 69%) as a white solid; mp 170-174 °C (Dec.); IR (cm^{-1}) 1743, 1522, 1446, 1363, 1296, 1228, 1171, 1090, 1039; ^{1}H-NMR (DMSO-d_6) δ 2.33 (s, 3H), 2.95 (s, 3H), 4.24 (d, *J* = 17.5 Hz, 2H), 4.47 (d, *J* = 17.5 Hz, 2H), 7.05 (brs, 1H), 7.36-7.42 (m, 3H), 7.75 (d, *J* = 2.0 Hz, 1H), 7.75 (d, *J* = 8.5 Hz, 2H), 8.13 (d, *J* = 9.0 Hz, 1H); Anal. Calcd for $C_{20}H_{18}N_2O_6BClS•1/4H_2O$ (C, H, N) (51.64, 4.01, 6.02). Found (51.80, 3.73, 5.74); HRMS calcd for $C_{20}H_{19}N_2O_6BClS$ [M+H] 461.0740, found 461.0740 (Δ 0.04).

5-Methoxycarbonyl-1-Ts-1*H*-indole-2-MIDA boronate (21): Prepared from 4-methoxycarbonyl-2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **21** (592.8 mg, 61%) as a white solid; mp 246-250 °C (Dec.); IR (cm^{-1}) 1743, 1716, 1369, 1369, 1230, 1171, 1136, 1090, 1031, 1003; ^{1}H-NMR (DMSO-d_6) δ 2.33 (s, 3H), 2.96 (s, 3H), 3.86 (s, 3H), 4.25 (d, *J* = 17.5 Hz, 2H), 4.48 (d, *J* = 17.5 Hz, 2H), 7.20 (d, *J* = 0.5 Hz, 1H), 7.40 (d, *J* = 8.0 Hz, 2H), 7.91-7.98 (m, 3H), 8.25 (d, *J* = 9.0 Hz, 1H), 8.29 (d, *J* = 1.5 Hz, 1H); Anal. Calcd for $C_{22}H_{21}N_2O_8BS•1/4H_2O$ (C, H, N) (54.06, 4.43, 5.73). Found (53.86, 4.05, 5.49); HRMS calcd for $C_{20}H_{22}N_2O_8BS$ [M+H] 485.1184, found 485.1183 (Δ 0.19).

6-Methoxycarbonyl-1-Ts-1*H*-indole-2-MIDA boronate (22): Prepared from 5-methoxycarbonyl-2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) afforded **22** (820.7 mg, 85%) as a pale yellow, amorphous solid; IR (cm^{-1}) 1739, 1716, 1558, 1541, 1456, 1419, 1373, 1228, 1205, 1091; ^{1}H-NMR (DMSO-d_6) δ 2.32 (s, 3H), 2.95 (s, 3H), 3.91 (s, 3H), 4.24 (d, *J* = 17.5 Hz, 2H), 4.48 (d, *J* = 17.5 Hz, 2H), 7.16 (d, *J* = 0.5 Hz, 1H), 7.41 (d, *J* = 8.0 Hz, 2H), 7.75-7.79 (m,

1H), 7.81-7.85 (m, 2H), 7.87 (dd, *J* = 1.5 Hz, 8.0 Hz, 1H), 8.77 (d, *J* = 0.5 Hz, 1H); HRMS calcd for $C_{22}H_{22}N_2O_8BS$ [M+H] 485.1184, found 485.1188 (Δ 0.48).

5-Trifloromethyl-1-Ts-1*H*-indole-2-MIDA boronate (23): Prepared from 4-trifluoromethyl-2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and recrystallization from EtOH afforded **23** (495.1 mg, 50%) as a white solid; mp 221-224 °C (Dec.); ^{1}H-NMR (DMSO-d_6) δ 2.33 (s, 3H), 2.95 (s, 3H), 4.25 (d, *J* = 17.5 Hz, 2H), 4.49 (d, *J* = 17.5 Hz, 2H), 7.20 (s, 1H), 7.41 (brd, *J* = 8.0 Hz, 2H), 7.69 (dd, *J* = 1.5 Hz, 9.0 Hz, 1H), 7.94 (brd, *J* = 8.5 Hz, 2H), 8.09-8.12 (m, 1H), 8.33 (d, *J* = 9.0 Hz, 1H); Anal. Calcd for $C_{21}H_{18}BF_3N_2O_6S$ (C, H, N) (51.03, 3.67, 5.67). Found (50.69, 3.42, 5.55); HRMS calcd for $C_{21}H_{19}O_6N_2BF_3S$ [M+H] 495.1003, found 495.1003 (Δ 0.07).

5-Methoxy-1-Ts-1*H*-indole-2-MIDA boronate (24): Prepared from 4-methoxy-2-iodo-1-Ts-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and recrystallization from EtOH afforded **24** (409.3 mg, 45%) as a pale yellow solid; mp 184-187 °C; IR (cm^{-1}) 1739, 1527, 1456, 1363, 1338, 1298, 1203, 1169, 1088, 1032; ^{1}H-NMR (DMSO-d_6) δ 2.31 (s, 3H), 2.95 (s, 3H), 3.75 (s, 3H), 4.22 (d, *J* = 17.5 Hz, 2H), 4.46 (d, *J* = 17.5 Hz, 2H), 6.94-6.99 (m, 2H), 7.14 (d, *J* = 2.5 Hz, 1H), 7.37 (brd, *J* = 8.0 Hz, 2H), 7.86 (brd, *J* = 8.5 Hz, 2H), 8.00 (d, *J* = 9.0 Hz, 1H); Anal. Calcd for $C_{21}H_{21}N_2O_7BS•1/8H_2O$ (C, H, N) (55.00, 4.67, 6.10). Found (54.79, 4.34, 5.94); HRMS calcd for $C_{21}H_{22}N_2O_7BS$ [M+H] 457.1235, found 457.1540 (Δ 0.59).

5-Methoxy-1-Ns-1*H*-indole-2-MIDA boronate (25): Prepared from 4-methoxy-2-iodo-1-Ns-aniline and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and trituration with hot EtOH afforded **25** (392.1 mg, 40%) as a pale brown solid; mp 250-253 °C (Dec.); IR (cm^{-1}) 1749, 1541, 1458, 1365, 1300, 1200, 1171, 1038, 1012; ^{1}H-NMR (DMSO-d_6) δ 2.91 (s, 3H), 3.79 (s, 3H), 4.16 (d, *J* = 17.5 Hz, 2H), 4.37 (d, *J* = 17.5 Hz, 2H), 6.54 (dd, *J* = 1.0 Hz, 8.0 Hz, 1H), 6.97 (dd, *J* = 2.5 Hz, 9.5 Hz, 1H), 7.14 (d, *J* = 0.5 Hz, 1H), 7.29 (d, *J* = 2.5 Hz, 1H), 7.72 (dd, *J* = 1.0 Hz, 7.5 Hz, 1H), 7.76 (d, *J* = 9.5 Hz, 1H), 7.88 (ddd, *J* = 1.0 Hz, 7.5 Hz, 7.5 Hz, 1H), 8.21 (dd, *J* = 1.0 Hz, 8.0 Hz, 1H); Anal. Calcd for $C_{20}H_{18}N_3O_9BS•1/4H_2O$ (C, H, N) (48.85, 3.79, 8.54). Found (48.85, 3.65, 8.23); HRMS calcd for $C_{20}H_{19}N_3O_9BS$ [M+H] 488.0930, found 488.0935 (Δ 0.55).

1-Ts-1*H*-pyrrolo[2,3-*b*]pyridine-2-MIDA boronate (26): Prepared from 3-iodo-2-*N*-Ts-aminopyridine and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and trituration with hot EtOH afforded **26** (476.1 mg, 56%) as a pale yellow solid; mp 166-170 °C; IR (cm^{-1}) 1743, 1363, 1340, 1306, 1250, 1176, 1090, 1032, 1009; ^{1}H-NMR (DMSO-d_6) δ 2.35 (s, 3H), 3.06 (s, 3H), 4.28 (d, *J* = 17.5 Hz, 2H), 4.50 (d, *J* = 17.5 Hz, 2H), 7.03 (s, 1H), 7.30 (dd, *J* = 4.5 Hz, 8.0 Hz, 1H), 7.43 (brd, *J* = 8.5 Hz, 2H), 8.05 (dd, *J* = 1.5 Hz, 8.0 Hz, 1H), 8.15 (brd, *J* = 8.5 Hz, 2H), 8.41 (dd, *J* = 1.5 Hz, 4.5 Hz, 1H); Anal. Calcd for $C_{19}H_{18}N_3O_6BS•1/4H_2O$ (C, H, N) (52.86, 4.32, 9.73). Found (52.70, 4.28, 9.58); HRMS

calcd for $C_{19}H_{19}N_3O_6BS$ [M+H] 428.1087, found 428.1091 (Δ 0.46).

1-Ts-1*H*-pyrrolo[2,3-*c*]pyridine-2-MIDA boronate (27): Prepared from 4-iodo-3-*N*-Ts-aminopyridine and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and trituration with hot EtOH afforded **27** (395.3 mg, 46%) as a pale yellow solid; mp 216-220 °C (Dec.), ^{1}H-NMR (DMSO-d_6) δ 2.33 (s, 3H), 2.95 (s, 3H), 4.26 (d, *J* = 17.5 Hz, 2H), 4.50 (d, *J* = 17.5 Hz, 2H), 7.10 (d, *J* = 0.5 Hz, 1H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.67 (dd, *J* = 1.0 Hz, 5.0 Hz, 1H), 7.98 (d, *J* = 8.5 Hz, 2H), 7.88 (d, *J* = 5.0 Hz, 1H), 9.38 (s, 1H); Anal. Calcd for $C_{19}H_{18}N_3O_6BS$ (C, H, N) (53.41, 4.25, 9.84). Found (53.52, 3.99, 9.32); HRMS calcd for $C_{19}H_{19}N_3O_8BS$ [M+H] 428.1082, found 428.1084 (Δ 0.22).

1-Ns-1*H*-pyrrolo[2,3-*c*]pyridine-2-MIDA boronate (28): Prepared from 4-iodo-3-*N*-Ns-aminopyridine and ethynylboronic acid MIDA ester. Purification by flash chromatography (AcOEt) and trituration with hot EtOH afforded **28** (139.1 mg, 15%) as a pale yellow solid; mp 262-264 °C (Dec.); IR (cm^{-1}) 1757, 1537, 1427, 1369, 1357, 1292, 1227, 1217, 1182, 1171, 1147, 1070, 1011; ^{1}H-NMR (DMSO-d_6) δ 2.89 (s, 3H), 4.17 (d, *J* = 17.5 Hz, 2H), 4.38 (d, *J* = 17.5 Hz, 2H), 6.65 (dd, *J* = 1.0 Hz, 8.0 Hz, 1H), 7.26 (s, 1H), (d, *J* = 1.5 Hz, 1H), 7.76 (ddd, *J* = 1.0 Hz, 8.0 Hz, 8.0 Hz, 1H), 7.82 (dd, *J* = 1.0 Hz, 5.0 Hz, 1H), 7.93 (ddd, *J* = 1.0 Hz, 8.0 Hz, 8.0 Hz, 1H), 8.27 (dd, *J* = 1.0 Hz, 8.0 Hz, 1H), 8.48 (d, *J* = 5.0 Hz, 1H), 9.19 (s, 1H); Anal. Calcd for $C_{18}H_{15}N_4O_8BS$ (C, H, N) (47.18, 3.30, 12.23). Found (46.87, 3.27, 12.16); HRMS calcd for $C_{18}H_{16}N_4O_8BS$ [M+H] 459.0776, found 459.0776 (Δ 0.004).

General procedure for the preparation of 2-aryl product. 5-Methoxycarbonyl-2-phenylbenzofuran: 2 wt% DL-α-Tocopherolmethoxypolyeneglycol succinate solution (1.5 mL) was added to a mixture of 5-methoxycarbonylbenzofuran-2-MIDA boronate (200 mg, 0.604 mmol), (dtbpf)$PdCl_2$ (32 mg, 0.048 mmol) and bromobenzene (95 mg, 0.604 mmol) under N_2. Et_3N (0.25 mL, 1.81 mmol) was added to the suspension under N_2. The reaction mixture was vigorously stirred at 40 °C for 22 h under N_2. The resulting mixture was diluted with water to form a precipitate, which was filtered, washed with water and dissolved with $CHCl_3$. The obtained organic solutions were dried over Na_2SO_4 and concentrated. The residue was purified by flash chromatography (SiO_2, AcOEt : hexane = 30 : 70) to give 143.0 mg (94%) of white powder; mp 155-157 °C (EtOH, white powder); IR (cm^{-1}) 1739, 1716, 1435, 1373, 1306, 1230, 1157, 1114, 1806, 1036, 1018; ^{1}H-NMR ($CDCl_3$) δ 3.95 (s, 3H), 7.08 (d, *J* = 1.0 Hz, 1H), 7.36-7.41 (m, 1H), 7.44-7.50 (m, 2H), 7.55 (d, *J* = 8.5 Hz, 1H), 7.85-7.90 (m, 2H), 8.02 (dd, *J* = 1.5 Hz, 8.5 Hz, 1H), 8.32 (d, *J* = 1.5 Hz, 1H); Anal. Calcd for $C_{16}H_{12}O_3$ (C, H, N) (76.18, 4.79, 0.00). Found (76.15, 4.65, 0.00); HRMS calcd for $C_{16}H_{13}O_3$ [M+H] 253.0859, found 253.0859 (Δ 0.03).

ACKNOWLEDGEMENTS

I wish to thank Mr. Masakazu Nagasawa of this company for obtaining the high-resolution MS spectral data.

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