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Mild and General Access to Diverse 1*H*-Benzotriazoles *via* Diboron-Mediated N–OH Deoxygenation and Palladium-Catalyzed C–C and C–N Bond Formation

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Abstract: Benzotriazoles are a highly important class of compounds with broad-ranging applications in such diverse areas as medicinal chemistry, as auxiliaries in organic synthesis, in metallurgical applications, in aircraft deicing and brake fluids, and as antifog agents in photography. Although there are numerous approaches to N-substituted benzotriazoles, the essentially one general method to N-unsubstituted benzotriazoles is *via* diazotization of *ortho*-phenylenediamines, which can be limited by the availability of suitable precursors. Other methods to N-unsubstitued benzotriazoles are quite specialized. Although reduction of 1-hydroxy-1*H*-benzotriazoles is known, the reactions are not particularly convenient or broadly applicable. This presents a limitation for easy access to and availability of diverse benzotriazoles. Herein, we demonstrate a new, broadly applicable method to diverse 1*H*-benzotriazoles *via* a mild diboron reagent-mediated deoxygenation of 1-hydroxy-1*H*-benzotriazoles. We have also evaluated sequential deoxygenation and Pd-mediated C–C and C–N bond formation as a one-pot process for further diversification of the benzotriazole moiety. However, the results indicated that purification of the deoxygenation product prior to the Pd-mediated reaction is critical to the success of such reactions. The overall chemistry allows for facile access to a variety of new benzotriazoles. Along with the several examples presented, a discussion of the advantages of the approaches is described, as is also a possible mechanism for the deoxygenation process.

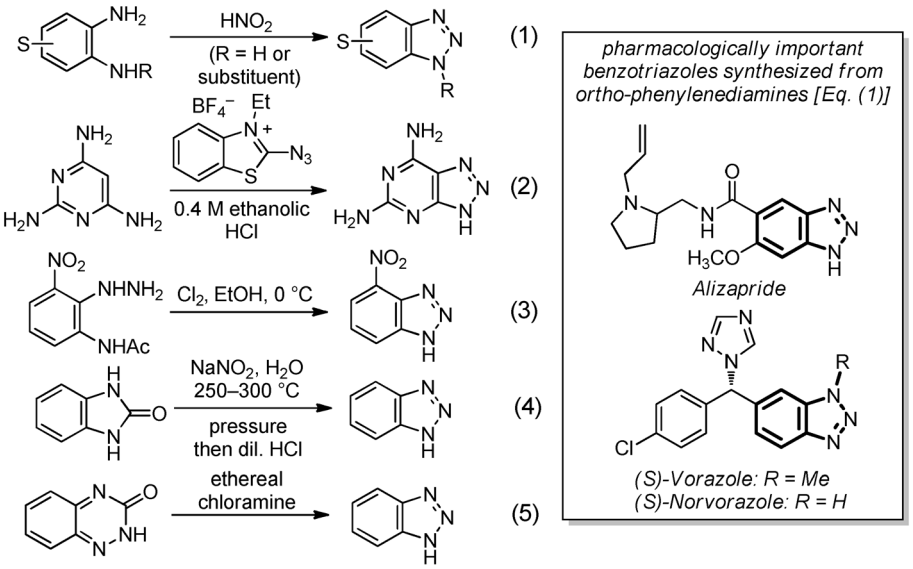
Keywords: benzotriazoles; deoxygenation; diboron reagents; 1-hydroxy-1*H*-benzotriazoles; reduction

Introduction

As a class, benzotriazoles (Bts) are highly important in a variety of applications. As examples, benzotriazole (Bt) and its derivatives are medicinally and pharmacologically important, and many have significant antiviral activities.[1–3] Bt has been used for decades as a corrosion inhibitor for copper and copper alloys such as brass and bronze. Mechanisms by which Bt inhibits corrosion of copper have been intensely investigated.[4] Because of its corrosion inhibiting properties of non-ferrous metals, Bt as well as 4- and 5-methyl-Bts are components in dishwashing detergent.[5] Bts are also found in formulations that contact metals, such as aircraft deicing and brake fluids, and in metal-cutting fluids.[6] In photographic applications Bts are used as antifog agents.[7]

Bts are also powerful entities in synthesis. As examples, Bt is a versatile synthetic auxiliary in diverse transformations,[8] aminoacyl-Bt derivatives (several now commercially available) are reagents for peptide assembly and synthesis of peptide conjugates,[9] and Bts have been used as ligands in cross-coupling reactions.[10]

By contrast to the numerous methods for synthesis of N-substituted Bts (see the Supporting Information for a compilation of several methods), there are far fewer ones to N-unsubstituted Bts, i.e., 1*H*-benzotriazoles (1*H*-Bts). The most common approach, limited by the availability of appropriate precursors, is *via* diazotization of *ortho*-phenylenediamines [Scheme 1,



Scheme 1. Other methods for the synthesis of 1*H*-benzotriazoles.

Eq. (1)]. When appropriate precursors are available, this method can be used for synthesis of both 1*H*-Bts and N-substituted Bts[11,12] The syntheses of alizapride, an antiemetic used for treating postoperative nausea and vomiting,[13] and the aromatase inhibitor vorazole,[14] exemplify this chemistry (structures shown in Scheme 1).

Some other specialized approaches to 1*H*-Bts are shown in Scheme 1. These involve diazo transfer [Eq. (2)],[15] oxidation of an *ortho*-acetamidophenylhydrazine by Cl_2 [Eq. (3)],[16] high-temperature and high-pressure reaction of benzimidazolones with $NaNO_2$ [Eq. (4)],[17] and reaction of benzo-1,2,4-triazin-3-(2*H*)-one with ethereal chloramine [Eq. (5)].[18]

A general approach to 1*H*-Bts would be the reduction of 1-hydroxy-1*H*-Bts and methods for this have been reported. Limited use of SmI_2 and PCl_3 has been reported to deoxgenate polymer-bound 1-hydroxy-1*H*-Bt.[19] From the amount of the resulting polymer loading reported, significant excesses of PCl_3 and SmI_2 seem to be needed for this reduction, and these methods have not been assessed for general applicability. Other reductions involving the use of Fe powder in dilute HCl at 86 °C.[20] $H_2/Et_3N/FeCl_2/Pt$-C at 80 °C and at 0.6 MPa (~6 atm),[21] and $Pb/Al/H_2O$ with dropwise addition of HCl at 100 °C[22] have been reported in the patent literature. The conditions used do not appear particularly convenient and could pose functional group incompatibilities.

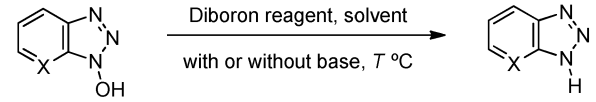
We have recently become interested in the scope of reductions that can be mediated by diboron reagents. Such reagents have been briefly investigated for the reduction of three amine *N*-oxides,[23] and in prior work we had discovered an unusual deoxygenation of O^6-(benzotriazolyl)inosine and deoxyinosine with bis(pinacolato)diboron [$(pinB)_2$] and Cs_2CO_3.[24] These had led us to develop a general reduction of amine *N*-oxides to amines using $(pinB)_2$ and bis(catecholato)diboron [$(catB)_2$], and such reactions could also be conducted in water.[25] Although reduction of the *zwitterionic* amine *N*-oxides was readily accomplished, an intriguing question is whether *charge neutral* N–OH bonds, such as those in 1-hydroxy-1*H*-Bts, can be reduced to NH groups by diboron reagents.

Results and Discussion

Feasibility of the N–OH→NH reduction was tested with commercially available HOBt and HOAt using $(pinB)_2$, $(catB)_2$, and $B_2(OH)_4$. MeCN and H_2O were tested as solvents, and DBU and Et_3N were tested as bases. Results from these initial experiments are shown in Table 1.

From the preliminary analysis, several factors come to light. (i) All three diboron reagents tested are effective for the reduction, both in MeCN and in water, but reactions in water present some product isolation problems. (ii) Reactions benefit significantly by addition of a base, indicating that deprotonation of HOBt and HOAt facilitates reaction at the boron center. In MeCN/H_2O the pK_a values of HOBt and HOAt are estimated at ~5.7 and ~4.0, respectively.[26] Thus, 1-hydroxy-1*H*-Bts can be readily deprotonated by Et_3N and DBU. (iii) $B_2(OH)_4$ is more reactive than $(pinB)_2$, consistent with a recent observation.[27] (iv) In the reduction of HOAt (**2**) formation of a significant polar material, possibly an amine adduct, was observed. This diminished over an 8 h reaction time to yield 1*H*-7-azabenzotriazole in excellent yield. In this case,

Table 1. Evaluation of conditions for the deoxygenation of HOBt (**1**) and HOAt (**2**).



HOBt (**1**): X = CH
HOAt (**2**): X = N

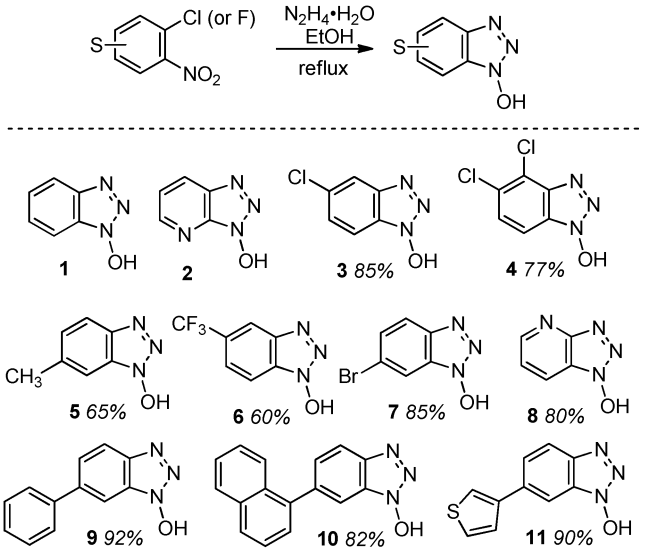
Entry	Substrate	Conditions[a]	Conversion, ***Yield*** [%][b]
1	**1**	$(pinB)_2$, MeCN, r.t., 12 h	~5%, NA
2	**1**	$(pinB)_2$, MeCN, 50 °C, 24 h	~50%, NA
3	**1**	$(pinB)_2$, MeCN, 80 °C, 12 h	~95%, ***92***
4	**2**	$(pinB)_2$, MeCN, 80 °C, 12 h	~95%, ***90***
5	**1**	$(pinB)_2$, DBU, MeCN, 50 °C, 1 h	100%, ***96***
6	**1**	$(pinB)_2$, Et_3N, MeCN, 50 °C, 0.5 h	100%, ***98***
7	**2**	$(pinB)_2$, Et_3N, MeCN, 50 °C, 8 h	100%, ***94***
8	**1**	$B_2(OH)_4$, H_2O, 85 °C, 6 h	100%, ***95***
9[c]	**2**	$B_2(OH)_4$, H_2O, 85 °C, 12 h	95%, ***75***
10	**1**	$(catB)_2$, Et_3N, MeCN, 50 °C, 0.5 h	100%, ***90***
11	**2**	$(catB)_2$, Et_3N, MeCN, 50 °C, 0.5 h	100%, ***88***
12	**1**	$B_2(OH)_4$, Et_3N, MeCN, r.t., 1.2 h	98%, ***95***
13	**1**	$B_2(OH)_4$, Et_3N, MeCN, 50 °C, 0.5 h	100%, ***95***
14	**2**	$B_2(OH)_4$, Et_3N, MeCN, 50 °C, 8 h	100%, ***92***
15	**1**	$B_2(OH)_4$, Cs_2CO_3, MeCN, 50 °C, 1 h	98%, ***92***
16	**2**	$B_2(OH)_4$, Cs_2CO_3, MeCN, 50 °C, 1 h	100%, ***95***
17	**1**	$B_2(OH)_4$, K_3PO_4, H_2O, 85 °C, 24 h	~10%, NA[d]

[a] Reactions with performed with 1.2 equiv. of the diboron reagent and where applicable 1.2 equiv. of base.
[b] Yields reported are of isolated and purified products.
[c] Reaction required 1.7 equiv. of $B_2(OH)_4$.
[d] Multiple spots were observed by TLC.

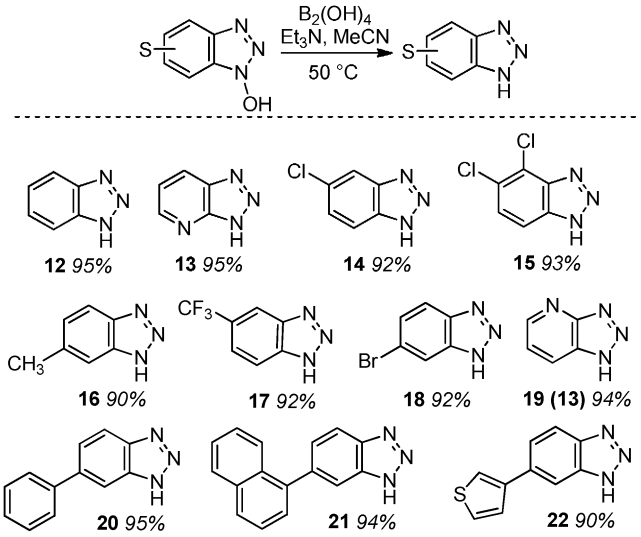
use of Cs_2CO_3 eliminated this problem, producing a relatively fast reaction, but work-up was cumbersome due to a pasty nature of the reaction mixture. When 0.5 or 1 equiv. of Et_3N was added to a solution of HOAt in MeCN, a polar material formed in each case. These adducts were isolated and ^1H NMR spectra obtained and these clearly showed resonances from Et_3N (see the mechanistic discussion below and the Supporting Information). The formation of an adduct is comparable to hydrazine adducts with 1-hydroxyazabenzotriazoles.[28]

Next, several new 1-hydroxy-1*H*-Bts **3**–**7** and 1-hydroxy-1*H*-4-aza-Bt **8** were synthesized by known methods[26,28,29] (Scheme 2, *Caution*[30]), essentially *via* a facile reaction of *ortho*-chloro or *ortho*-fluoro nitro aromatic compounds with hydrazine. Further, halo nitro aromatics are exceptionally activated toward oxidative addition to Pd and there are substantial differences in the ease with which this occurs for various C–halogen bonds. This can be leveraged for generating additional compound diversity with dihalo nitro aromatic compounds. To demonstrate this, compounds **9**–**11** were readily synthesized from 4-bromo-1-fluoro-2-nitrobenzene *via* reactions with phenyl-, 1-naphthyl-, and 3-thienylboronic acids using $Pd(PPh_3)_4$ followed by reaction with hydrazine.

The 1-hydroxy-1*H*-Bts **1**–**11** were subjected to reaction with $B_2(OH)_4$ (1.2 equiv.) and Et_3N (1.2 equiv.) at 50 °C in MeCN, conditions which were determined to be optimal. Highly efficient reduction was observed



Scheme 2. 1-Hydroxy-1*H*-benzotriazoles selected for the analysis and yields of those synthesized.



Scheme 3. Various 1*H*-benzotriazoles synthesized.

in each case with isolated product yields of $\geq$90% (Scheme 3). Reactions were complete within 30 min except for compounds **2** and **8**, which required 8 h reaction times.

Further diversification of the benzotriazoles was then considered. Because boron-based by-products are generally considered benign we evaluated a tandem deoxygenation/C–C cross-coupling approach to substituted Bts as a one-pot process. For this, compound **7** was deoxygenated with $B_2(OH)_4$/Et_3N in MeCN at 50 °C. The crude reaction mixture was evaporated and reactions were performed with four arylboronic acids (data shown in parenthesis in Table 2).

For this attempted one-pot conversion, the combination of $Pd(PPh_3)_4$ (0.2 equiv.)/2 M aqueous Na_2CO_3 in 1,4-dioxane at 100 °C proved to be ineffective. On the other hand, dichloro[1,1′-bis(dicyclohexylphosphinyl)ferrocene]palladium(II) [$PdCl_2$(dcpf)] (0.2 equiv.)/K_3PO_4 (2 equiv.) in 1,4-dioxane at 100 °C led to product formation in some cases but the reactions were capricious. Similarly, we attempted aryl amination as a two-step, one-pot process using compound **7**, but the reactions were unsuccessful with a variety of catalysts. These data showed that the deoxygenation by-products could have a detrimental effect on the Pd-catalyzed reactions, contrary to expectation. However, due to the relatively sparse literature on such Pd-mediated reactions of benzotriazoles in comparison to other aromatic systems, we needed to ascertain whether the reactions themselves were problematic or whether such conversions could be effectively conducted in a more general manner. Therefore, we evaluated reactions of purified benzotriazole **18** with arylboronic acids and arylamines, the results from which are shown in Table 2.

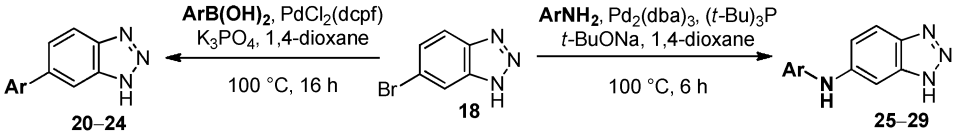
These data evidenced that Pd-catalyzed C–C and C–N reactions can be conducted in a general manner and that the deoxygenation by-products could inhibit these processes. Because compounds **20**, **21**, and **22** have been prepared either from 4-bromo-1-fluoro-2-nitrobenzene or from bromobenzotriazole **18**, we have compared the two approaches. Table 3 shows the overall three-step yields from the two sequences.

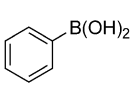
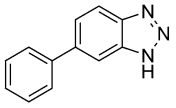
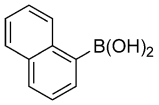
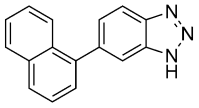
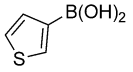
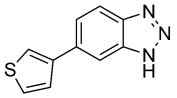
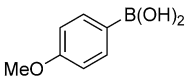
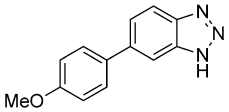
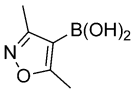
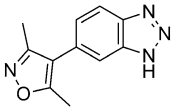
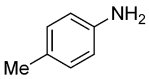
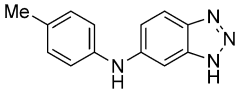
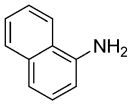
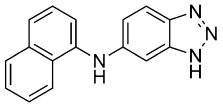
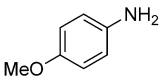
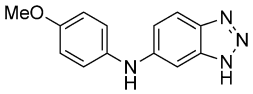
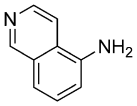
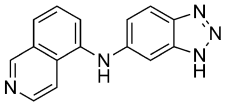
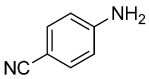
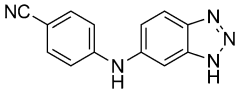
Between the two approaches Method 1 appears to be superior at least in the cases tested. There is another advantage to Method 1. Because halonitrobenzenes are very reactive, simple $Pd(PPh_3)_4$ is adequate for C–C bond formation. Nevertheless, both approaches are eminently useful depending upon specific needs. In contrast to the possibility for C–C cross-coupling prior to assembly of the benzotriazole moiety, it is less desirable to perform C–N bond formation on a dihalo nitro aromatic due to the possibility of unwanted S_NAr displacement of halide. Thus, the amination reactions are better conducted on the assembled benzotriazole.

We have also analyzed the possible mechanism of this reaction by ^1H and ^{11}B NMR. When HOBt and HOAt were independently exposed to Et_3N in MeCN-d_3, significant upfield shifts of the aromatic resonances were observed. This would be consistent with the formation of an electron-rich system by deprotonation. Because the reduction of HOAt is slower than that of HOBt, $(pinB)_2$ was added to the HOAt/Et_3N mixture in MeCN-d_3 and stirred at 50 °C. Aliquots were taken at regular intervals and assessed by ^1H and ^{11}B NMR. During the course of the reaction, the ^1H NMR spectrum showed disappearance of the resonances of what is presumably AtO^- and formation of a set of resonances corresponding to product. However, these new resonances were also upfield shifted. Addition of an aliquot of the reaction mixture to pure 1*H*-7-azabenzotriazole also caused an upfield shift of its resonances indicating a presently unknown interaction with the reaction components. Purification of the products however led to proton resonances at the expected chemical shifts.

Acquisition of ^{11}B NMR data of the reaction involving HOAt, Et_3N, and $(pinB)_2$ in MeCN-d_3 over a 3 h timeframe showed resonances from $(pinB)_2$ (δ = 30.6 ppm) and presumably $(pinB)_2O$ (δ = 22.4 ppm). Prolonged heating resulted in other ^{11}B resonances, possibly due to interactions of the nitrogenated compounds with the boron-containing materials. Although the deoxygenation of pyridine *N*-oxides by $(pinB)_2$ was more readily discerned by NMR[23] as compared to the conversion herein, we propose the mechanism shown in Scheme 4, where either the *N*-hydroxy and/or the *N*-oxide Bt tautomer[31] can be involved.

Table 2. Diversification of 1*H*-benzotriazoles *via* Pd-catalyzed C–C and C–N bond formation.



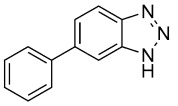
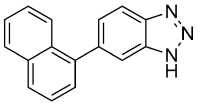
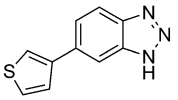
Entry	$ArB(OH)_2$ or $ArNH_2$	Product	Compound: *Yield*[a]
1			**20:** *90%*, 99.6,[b] (60%)[c,d]
2			**21:** *78%*, 99.8,[b] (NR)[e]
3			**22:** *88%*, 99.8,[b] (42)[c,d]
4			**23:** *75%*, 99.1,[b] (45)[c,d]
5			**24:** *60%*, 99.1[b]
6			**25:** *80%*, 99.1[b]
7			**26:** *72%*, 99.2[b]
8			**27:** *70%*, 99.5[b]
9			**28:** *68%*, 98.2[b]
10			**29:** *65%*, 99.7[b]

[a] Yields reported are of isolated and purified products.
[b] Purity by UPLC analysis.
[c] Yield for the two-step, one-pot reaction.
[d] A significant amount of compound **18** from the deoxygenation step remained.
[e] No reaction was observed in the two-step, one-pot reaction, and only compound **18** from the deoxygenation step remained.

Conclusions

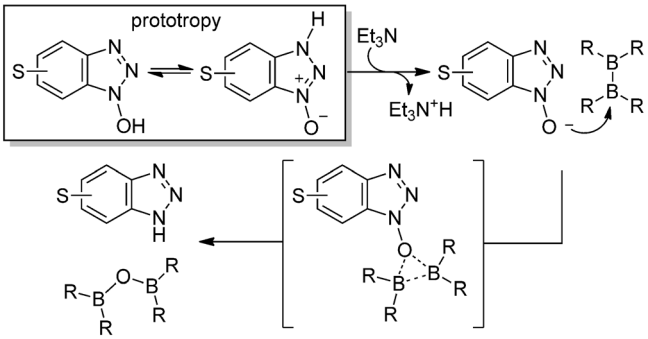
In summary, we have disclosed a previously unknown, mild, and general approach to 1*H*-benzotriazoles *via* a diboron reagent-mediated N–O deoxygenation of 1-hydroxy-1*H*-benzotriazoles. Using differential reactivities of C–halogen bonds towards Pd catalysts, additional compound diversity can be easily attained. Also, C–halogen bonds that can be reduced under other reductive conditions remain unaffected under these conditions. This offers a synthetic advantage for subsequent manipulations, such as the metal-catalyzed reactions described. In this context, we have evaluated a two-step, one-pot deoxygenation/Pd-catalysis protocol. However, we have found that removal of the deoxygenation by-products is essential for successful catalysis reactions. We have demonstrated diversification of the benzotriazole moiety *via* three Pd-cata-

Table 3. Comparison of two methods for diversification *via* C–C bond formation.

Entry	Final product	Overall yield *via* method 1[a] *vs.* method 2[b]
1		**20:** 83% *vs.* 70%
2		**21:** 69% *vs.* 61%
3		**22:** 74% *vs.* 69%

[a] Method 1: C–C reaction of 4-bromo-1-fluoro-2-nitrobenzene with the arylboronic acid, construction of the hydroxybenzotriazole, and then deoxygenation.

[b] Method 2: synthesis of compound **7**, deoxygenation to benzotriazole **18**, and then C–C reaction with the arylboronic acid.



Scheme 4. A possible mechanism for the deoxygenation.

lyzed approaches, all of which appear generally applicable: (i) C–C bond formation prior to formation of the 1-hydroxy-1*H*-benzotriazoles and then deoxygenation, (ii) C–C bond formation on the deoxygenated product, and (iii) C–N bond formation on the deoxygenated product. This chemistry further demonstrates an untapped potential of diboron reagents for novel transformations such as the N–OH→NH reduction shown here, and complements the reduction of amine *N*-oxides by diboron reagents.

Experimental Section

General Experimental Considerations

Thin-layer chromatography was performed on 200 μm aluminum-foil-backed silica gel plates. Bis(pinacolato)diboron $(pinB)_2$, bis(catecholato)diboron $(catB)_2$, tetrahydroxydiboron $B_2(OH)_4$, all arylboronic acids, arylamines, $PdCl_2(dcpf)$, $Pd_2(dba)_3$, $(t\text{-Bu})_3P$, and all other reagents were obtained from commercial suppliers and were used without further purification. Column chromatographic purifications were performed on 100–200 mesh silica gel. MeCN was distilled over CaH_2, 1,4-dioxane was distilled over $NaBH_4$ and then freshly distilled over Na prior to use. EtOAc and hexanes were distilled over $CaSO_4$, and commercial CH_2Cl_2 was redistilled. Other commercially available compounds were used without further purification. ^{1}H NMR spectra were recorded at 400 MHz in the solvents indicated and are referenced to residual protonated solvent resonances. ^{13}C NMR spectra were recorded at 100 MHz in the solvents indicated and are referenced to the solvent resonances. Chemical shifts (δ) are reported in parts per million (ppm) and coupling constants (J) are in hertz (Hz). Standard abbreviations are used to designate resonance multiplicities. ^{19}F NMR spectra were recorded at 376 MHz in the solvents indicated.

Synthesis of Precursors to Compounds 9, 10 and 11[32]

4-Fluoro-3-nitrobiphenyl: In a 100-mL oven-dried, round-bottomed flask equipped with a stirring bar were placed 5-bromo-2-fluoronitrobenzene (2.0 g, 9.13 mmol) and phenylboronic acid (1.22 g, 10.0 mmol) in 1:1 toluene/EtOH (40 mL). Aqueous 2 M Na_2CO_3 (10 mL) was added, the mixture was sparged with argon gas for 5 min, and $Pd(PPh_3)_4$ (0.31 g, 3 mol%) was added. The reaction mixture was heated at reflux for 2 h and monitored by TLC. Upon completion of the reaction the mixture was concentrated, diluted with EtOAc, and washed with water. The aqueous layer was extracted with EtOAc (2×). The organic layer was dried over anhydrous Na_2SO_4 and evaporated under reduced pressure. Chromatography of the crude material on a silica gel column using 5% EtOAc in hexanes gave the title compound as a pale yellow solid; yield: 1.88 g (95%); R_f (SiO_2/10% EtOAc in hexanes) = 0.53. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.25 (dd, J = 2.1, 7.0 Hz, Ar-H, 2H), 7.84–7.80 (m, Ar-H, 1H), 7.56 (dd, J = 2.0, 8.5 Hz, Ar-H, 1H), 7.49–7.39 (m, Ar-H, 3H), 7.37 (t, J = 9.6 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.6 (d, $J_{C,F}$ = 264.1 Hz), 138.3 (d, $J_{C,F}$ = 3.8 Hz), 137.6, 133.8 (d, $J_{C,F}$ = 8.4 Hz), 129.1, 128.5, 126.9, 124.2 (d, $J_{C,F}$ = 2.2 Hz), 118.7 (d, $J_{C,F}$ = 20.5 Hz). ^{19}F NMR (376 MHz, $CDCl_3$): δ = −120.3.

1-(4-Fluoro-3-nitrophenyl)naphthalene: Synthesized as described for 4-fluoro-3-nitrobiphenyl, using 5-bromo-2-fluoronitrobenzene (2.0 g, 9.13 mmol), naphthalen-1-ylboronic acid, (1.72 g, 10.0 mmol), 2 M aqueous Na_2CO_3 (10 mL), and $Pd(PPh_3)_4$ (0.31 g, 3 mol%) in 1:1 toluene/EtOH (40 mL) at reflux for 2 h. Work-up as described above and chromatography of the crude material on a silica gel column using 5% EtOAc in hexanes gave the title compound as an off-white solid; yield: 2.19 g (90%); R_f (SiO_2/10% EtOAc in hexanes) = 0.53. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.16 (dd, J = 2.2, 7.2 Hz, Ar-H, 1H), 8.92 (dd, J = 4.8, 7.6 Hz, Ar-H, 2H), 7.72–7.69 (m, Ar-H, 2H), 7.53–7.44 (m, Ar-H, 3H), 7.40–7.35 (m, Ar-H, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.7 (d, $J_{C,F}$ = 264.1 Hz), 137.6 (d, $J_{C,F}$ = 4.6 Hz), 137.2 (d, $J_{C,F}$ = 8.0 Hz), 136.9, 136.3, 133.8, 131.0, 128.9, 128.6, 127.2, 127.1, 126.8, 126.2, 125.2, 124.7, 118.2 (d, $J_{C,F}$ = 21.2 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ = −119.8.

3-(4-Fluoro-3-nitrophenyl)thiophene: Synthesized as described for 4-fluoro-3-nitrobiphenyl, using 5-bromo-2-fluoro-

nitrobenzene (2.0 g, 9.13 mmol), 3-thienylboronic acid, (1.28 g, 10.0 mmol), 2 M aqueous Na_2CO_3 (10 mL), and $Pd(PPh_3)_4$ (0.31 g, 3 mol%) in 1:1 toluene/EtOH (40 mL), at reflux for 2 h. Work-up as described above and chromatography of the crude material on a silica gel column using 5% EtOAc in hexanes gave the title compound as an as off-white solid; yield: 1.87 g (92%); R_f (SiO_2/10% EtOAc in hexanes) = 0.43. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.24 (dd, J = 2.1, 7.0 Hz, Ar-H, 1 H), 7.83–7.79 (m, Ar-H, 1 H), 7.51 (d, J = 4.0 Hz, Ar-H, 1 H), 7.45 (t, J = 4.0 Hz, Ar-H, 1 H), 7.36–7.25 (m, Ar-H, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 154.4 (d, $J_{C,F}$ = 264.1 Hz), 138.7, 137.5, 133.0 (d, $J_{C,F}$ = 8.4 Hz), 127.4, 125.7, 123.5 (d, $J_{C,F}$ = 2.3 Hz), 121.9, 118.7 (d, $J_{C,F}$ = 21.2 Hz); ^{19}F NMR (376 MHz, $CDCl_3$): δ = −120.2.

General Procedure for the Synthesis of 1-Hydroxy-1*H*-benzotriazoles

A mixture of the appropriate *ortho*-chloronitro- or *ortho*-fluoronitrobenzene and hydrazine hydrate were heated at reflux in absolute EtOH for the period of time indicated for each compound. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3. The solution was extracted with Et_2O to remove any starting material and then acidified with concentrated HCl to precipitate the product, which was filtered, washed with water, and dried to obtain the various 1-hydroxy-1*H*-benzotriazoles.

5-Chloro-1*H*-benzo[*d*][1,2,3]triazol-1-ol (3): Synthesized using 2,4-dichloro-1-nitrobenzene (1.5 g, 7.85 mmol) and hydrazine hydrate (0.77 mL, 15.70 mmol) in absolute EtOH (10 mL) at reflux over 36 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **3** as an off-white solid; yield: 1.13 g (85%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.37. IR (KBr): ν = 3461, 1342, 747 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.85 (br s, OH, 1 H), 8.14 (s, Ar-H, 1 H), 7.80 (d, J = 8.7 Hz, Ar-H, 1 H), 7.58 (d, J = 8.7 Hz, Ar-H, 1 H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 143.3, 129.1, 127.9, 126.6, 118.4, 111.2; HR-MS (ESI/TOF): m/z = 170.0126, calcd. for $C_6H_5ClN_3O$ $[M+H]^+$: 170.0116.

4,5-Dichloro-1*H*-benzo[*d*][1,2,3]triazol-1-ol (4): Synthesized using 1,2,3-trichloro-4-nitrobenzene (1.5 g, 6.66 mmol) and hydrazine hydrate (0.65 mL, 13.33 mmol) in absolute EtOH (10 mL) at reflux over 36 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **4** as a white solid; yield: 1.04 g (77%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.40. IR (KBr): ν = 3494, 1385, 796 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 7.59 (d, 1 H, Ar-H, J = 8.8 Hz), 7.55 (d, 1 H, Ar-H, J = 8.8 Hz); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 140.8, 127.7, 127.5, 126.7, 120.9, 110.2; HR-MS (ESI/TOF): m/z = 203.9724, calcd. for $C_6H_4Cl_2N_3O$ $[M+H]^+$: 203.9726.

6-Methyl-1*H*-benzo[*d*][1,2,3]triazol-1-ol (5):[33] Synthesized using 1-chloro-4-methyl-2-nitrobenzene (1.0 g, 5.84 mmol) and hydrazine hydrate (0.57 m, 11.69 mmol) in absolute EtOH (8 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **5** as a white solid; yield: 0.56 g (65%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.34. IR (KBr): ν = 3431, 1388, 809 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.24 (br s, OH, 1 H), 7.87 (d, J = 8.5 Hz, Ar-H, 1 H), 7.49 (s, Ar-H, 1 H), 7.25 (d, J = 8.5 Hz, Ar-H, 1 H), 2.49 (s, CH_3, 3 H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 141.6, 137.6, 128.2, 126.8, 118.6, 108.3, 21.3; HR-MS (ESI/TOF): m/z = 150.0659, calcd. for $C_7H_8N_3O$ $[M+H]^+$: 150.0662.

5-(Trifluoromethyl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (6): Synthesized using 2-chloro-1-nitro-4-(trifluoromethyl)benzene (2.0 g, 8.88 mmol) and hydrazine hydrate (0.88 g, 17.76 mmol) in absolute EtOH (13 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (25 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **6** as a white solid; yield: 1.08 g (60%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.33. IR (KBr): ν = 3437, 1330, 809 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 14.0 (br s, OH, 1 H), 8.51 (s, Ar-H, 1 H), 7.99 (d, J = 8.7 Hz, Ar-H, 1 H), 7.85 (d, J = 8.7 Hz, Ar-H, 1 H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 141.9, 129.2, 124.7 (q, $J_{C,F}$ = 270.9 Hz), 125.3 (q, $J_{C,F}$ = 31.8 Hz), 123.5, 117.9 (d, $J_{C,F}$ = 4.6 Hz), 111.3; ^{19}F NMR (376 MHz, DMSO-d_6): δ = −63.2 (with internal standard TFA-d δ = −78.5); HR-MS (ESI/TOF): m/z = 204.0391, calcd. for $C_7H_3F_3N_3O$ $[M+H]^+$: 204.0380.

6-Bromo-1*H*-benzo[*d*][1,2,3]triazol-1-ol (7): Synthesized using 4-bromo-1-fluoro-2-nitrobenzene (3.0 g, 13.70 mmol) and hydrazine hydrate (1.34 mL, 27.40 mmol) in absolute EtOH (20 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (30 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **7** as an off-white solid; yield: 2.48 g (85%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.38. IR (KBr): ν = 3436, 1206, 803 cm^{-1}; ^{1}H NMR (400 MHz, DMSO-d_6): δ = 13.45 (br s, OH, 1 H), 7.96 (m, Ar-H, 2 H), 7.52 (d, J = 8.5 Hz, Ar-H, 1 H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 141.7, 128.7, 127.6, 120.9, 120.2, 112.2. HR-MS (ESI/TOF): m/z = 213.9614, calcd. for $C_6H_5BrN_3O$ $[M+H]^+$: 213.9611.

1*H*-[1,2,3]triazolo[4,5-*b*]pyridin-1-ol (8):[26] Synthesized using 2-chloro-3-nitropyridine (1.0 g, 6.32 mmol) and hydrazine hydrate (0.62 mL, 12.64 mmol) in absolute EtOH (10 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (20 mL) to remove the starting material and aqueous layer was acidified with concentrated HCl. The product that precipitated slowly over 12 h was filtered, washed with water, and dried to obtain compound **8** was obtained as an off-white solid; yield: 0.68 g (80%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.21. IR (KBr): ν = 3457, 1396,

777 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): $\delta = 8.36$ (dd, $J =$ 1.5, 4.1 Hz, Ar-H, 1H), 7.91–7.89 (m, Ar-H, 1H), 7.03–7.00 (m, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 153.8$, 146.5, 120.8, 118.9, 116.3; HR-MS (ESI/TOF): $m/z =$ 137.0475, calcd. for $C_5H_5N_4O$ $[M+H]^+$: 137.0458.

6-Phenyl-1*H*-benzo[*d*][1,2,3]triazol-1-ol (9): Synthesized using 4-fluoro-3-nitrobiphenyl (1.0 g, 4.67 mmol) and hydrazine hydrate (0.45 mL, 9.34 mL) in absolute EtOH (8 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (20 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **9** as a white solid; yield: 0.89 g (92%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.42. IR (KBr): $\nu = 3565$, 1088, 695 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): $\delta = 7.77$ (d, $J = 8.5$ Hz, Ar-H, 1H), 7.62 (d, $J = 7.4$, Hz, Ar-H 2H), 7.55 (s, Ar-H, 1H), 7.47 (t, $J = 8.11$ Hz, Ar-H, 3H), 7.37 (t, $J = 7.2$ Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 142.9$, 140.7, 136.3, 129.3, 128.5, 127.6, 127.4, 123.1, 119.1, 108.6; HR-MS (ESI/TOF): $m/z = 212.0823$, calcd. for $C_{12}H_{10}N_3O$ $[M+H]^+$: 212.0819.

6-(Naphthalen-1-yl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (10): Synthesized using 1-(4-fluoro-3-nitrophenyl) naphthalene (1.0 g, 3.74 mmol) and hydrazine hydrate (0.36 mL, 7.48 mmol) in absolute EtOH (8 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (30 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **10** as a white solid; yield: 0.80 g (82%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.41. IR (KBr): $\nu = 3448$, 1300, 754 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): $\delta = 13.98$ (br s, OH, 1H), 8.11 (d, $J = 8.5$ Hz, Ar-H, 1H), 8.05 (t, $J = 8.5$ Hz, Ar-H, 2H), 7.80 (d, $J = 8.3$ Hz, Ar-H, 1H), 7.74 (s, Ar-H, 1H), 7.64–7.48 (m, Ar-H, 5H); ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 142.2$, 139.0, 138.5, 133.3, 130.8, 128.3, 128.2, 128.1, 127.3, 126.9, 126.5, 126.0, 125.5, 125.0, 118.9, 110.2; HR-MS (ESI/TOF): $m/z = 262.0977$, calcd. for $C_{16}H_{12}N_3O$ $[M+H]^+$: 262.0975.

6-(Thien-3-yl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (11): Synthesized using 3-(4-fluoro-3-nitrophenyl)thiophene (1.0 g, 4.47 mmol) and hydrazine hydrate (0.44 mL, 8.95 mmol) in absolute EtOH (10 mL) at reflux over 24 h. After removal of the solvent under reduced pressure, the residue was dissolved in 10% aqueous Na_2CO_3 (20 mL). The solution was extracted with Et_2O (20 mL) and then acidified with concentrated HCl. The precipitated product was filtered, washed with water, and dried to obtain compound **11** as a white solid; yield: 0.87 g (90%); R_f (SiO_2/10% MeOH, 1% Et_3N in CH_2Cl_2) = 0.33. IR (KBr): $\nu = 3408$, 1370, 773 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): $\delta = 7.87$ (s, Ar-H, 1H), 7.81 (d, $J =$ 8.7 Hz, Ar-H, 1H), 7.68 (s, Ar-H, 1H), 7.64–7.60 (m, Ar-H, 2H), 7.54 (d, $J = 4.8$ Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): $\delta = 142.2$, 141.1, 132.2, 128.2, 127.1, 126.4, 122.8, 121.4, 118.9, 106.6; HR-MS (ESI/TOF): $m/z = 218.0382$, calcd. for $C_{10}H_8N_3SO$ $[M+H]^+$: 218.0383.

General Procedure for the Synthesis of Benzotriazoles

In a clean, dry 8-mL vial equipped with a stirring bar, the 1-hydroxy-1*H*-benzotriazole was dissolved in MeCN. Et_3N (1.2 equiv.) was added and the reaction mixture was stirred at room temperature for 30 min. Then $B_2(OH)_4$ (1.2 equiv.) was added and the resulting reaction mixture was stirred for 30 min (8 h for substrates **2** and **8**) at 50 °C. After completion of the reaction, the mixture was concentrated and crude material was purified by chromatography on a silica gel column by elution with 10–50% EtOAc in hexanes and in the case of compound **13** with 0–5% MeOH in CH_2Cl_2.

1*H*-Benzo[*d*][1,2,3]triazole (12): Synthesized using 1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 1.48 mmol), Et_3N (0.24 mL, 1.77 mmol), and $B_2(OH)_4$ (159 mg, 1.77 mmol) in MeCN (2 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **12** as a white solid; yield: 168 mg (95%); R_f (SiO_2/50% EtOAc in hexanes) = 0.46. IR (KBr): $\nu = 3468$, 1207, 740 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): $\delta = 7.95$ (dd, $J = 3.1$, 6.3 Hz, Ar-H, 2H), 7.47 (dd, $J = 3.1$, 6.3 Hz, Ar-H, 2H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): $\delta = 138.7$, 125.4, 114.9; HR-MS (ESI/TOF): $m/z = 120.0562$, calcd. for $C_6H_6N_3$ $[M+H]^+$: 120.0557.

3*H*-[1,2,3]Triazolo[4,5-*b*]pyridine (13): Synthesized using 3*H*-[1,2,3]triazolo[4,5-*b*]pyridin-3-ol (200 mg, 1.47 mmol), Et_3N (0.24 mL, 1.76 mmol), and $B_2(OH)_4$ (158 mg, 1.76 mmol) in MeCN (2 mL) over 8 h at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with MeOH in CH_2Cl_2 gave compound **13** as a white solid; yield: 166 mg (95%); R_f (SiO_2/10% MeOH in CH_2Cl_2) = 0.10. IR (KBr): $\nu = 3436$, 1399, 783 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): $\delta = 8.75$ (dd, $J = 1.2$, 4.1 Hz, Ar-H, 1H), 8.47 (dd, $J = 1.0$, 8.3 Hz, Ar-H, 1H), 7.54 (dd, $J = 4.4$, 8.3 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): $\delta = 151.2$, 149.3, 130.9, 124.9, 120.9; HR-MS (ESI/TOF): $m/z = 121.0513$, calcd. for $C_5H_5N_4$ $[M+H]^+$:121.0509.

5-Chloro-1*H*-benzo[*d*][1,2,3]triazole (14):[22] Synthesized using 5-chloro-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 1.17 mmol), Et_3N (0.19 mL, 1.41 mmol), and $B_2(OH)_4$ (142 mg, 1.41 mmol) in MeCN (1.6 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **14** as a white solid; yield: 166 mg (92%); R_f (SiO_2/50% EtOAc in hexanes) = 0.44. IR (KBr): $\nu = 3454$, 1392, 800 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): $\delta = 15.86$ (br s, 1H, NH), 8.01 (s, 1H, Ar-H), 7.95 (d, 1H, Ar-H, $J = 8.7$ Hz), 7.44 (d, 1H, Ar-H, $J = 8.7$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): $\delta = 139.4$, 138.2, 130.6, 126.2, 117.0, 114.5; HR-MS (ESI/TOF): $m/z = 154.0164$, calcd. for $C_6H_5ClN_3$ $[M+H]^+$: 154.0167.

4,5-Dichloro-1*H*-benzo[*d*][1,2,3]triazole (15): Synthesized using 4,5-dichloro-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.98 mmol), Et_3N (0.16 mL, 1.18 mmol), and $B_2(OH)_4$ (106 mg, 1.18 mmol) in MeCN (1.3 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **15** as a white solid;

yield: 171 mg (93%)(; R_f (SiO_2/50% EtOAc in hexanes)= 0.40. IR (KBr): ν=3458, 1439, 809 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6+1 drop of TFA-*d*): δ=7.93 (d, J= 8.8 Hz, Ar-H, 1H), 7.66 (d, J=8.8 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop of TFA-*d*): δ=139.6, 137.6, 128.2, 127.9, 118.7, 114.5; HR-MS (ESI/TOF): m/z= 187.9789, calcd. for $C_6H_4Cl_2N_3$ $[M+H]^+$: 187.9777.

6-Methyl-1*H*-benzo[*d*][1,2,3]triazole (16):[22] Synthesized using 6-methyl-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 1.34 mmol), Et_3N (0.22 mL, 1.61 mmol), and $B_2(OH)_4$ (144 mg, 1.61 mmol) in MeCN (1.81 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **16** as a white solid; yield: 160 mg (90%); R_f (SiO_2/50% EtOAc in hexanes)= 0.40. IR (KBr): ν=3456, 1440, 795 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6, 100 °C): δ=15.21 (brs, 1H, NH), 7.79 (d, 1H, Ar-H, J=4.8 Hz), 7.62 (s, 1H, Ar-H), 7.26 (d, 1H, Ar-H, J=8.0 Hz), 2.47 (s, 3H, CH_3); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop of TFA-*d*): δ=138.8, 138.1, 135.9, 127.3, 115.4, 113.0 21.2; HR-MS (ESI/TOF): m/z=134.0707, calcd. for $C_7H_8N_3$ $[M+H]^+$: 134.0713.

5-(Trifluoromethyl)-1*H*-benzo[*d*][1,2,3]triazole (17): Synthesized using 5-(trifluoromethyl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.98 mmol), Et_3N (0.16 mL, 1.18 mmol), and $B_2(OH)_4$ (105 mg, 1.18 mmol) in MeCN (1.3 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **17** as a white solid; yield: 169 mg (92%); R_f (SiO_2/50% EtOAc in hexanes)=0.43; IR (KBr): ν=3467, 1326, 824 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6+1 drop TAF-*d*): δ=16.04 (br s, NH, 1H), 8.42 (s, Ar-H, 1H), 8.13 (d, J=8.8 Hz, Ar-H, 1H), 7.77 (d, J=8.8 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop TFA-*d*): δ=140.0, 138.7, 124.6 (q, $J_{C,F}$= 270.2 Hz), 126.1 (q, $J_{C,F}$=31.9 Hz), 122.4 (d, $J_{C,F}$=3.0 Hz), 115.5, 114.9 (d, $J_{C,F}$=3.8 Hz); ^{19}F NMR (376 MHz, DMSO-d_6): δ=−59.7; HR-MS (ESI/TOF): m/z=188.0439, calcd. for $C_7H_5F_3N_3$ $[M+H]^+$: 188.0436.

6-Bromo-1*H*-benzo[*d*][1,2,3]triazole (18): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.93 mmol), Et_3N (0.15 mL, 1.12 mmol), and $B_2(OH)_4$ (101 mg, 1.12 mmol) in CH_3CN (1.3 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **18** as a white solid; yield: 170 mg (92%); R_f (SiO_2/50% EtOAc in hexanes)= 0.50. IR (KBr): ν=3436, 1206, 803 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ=15.89 (br s, NH, 1H), 8.20 (s, Ar-H, 1H), 7.92 (d, J=8.0 Hz, Ar-H, 1H), 7.58 (t, J=4.5 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop of TFA-*d*): δ=139.8, 137.9, 128.5, 118.3, 117.5, 116.9; HR-MS (ESI/TOF): m/z=197.9651, calcd. for $C_6H_5BrN_3$ $[M+H]^+$: 197.9662.

1*H*-[1,2,3]Triazolo[4,5-*b*]pyridine (19 same as compound 13): Synthesized using 1*H*-[1,2,3]triazolo[4,5-*b*]pyridine (200 mg, 1.47 mmol), Et_3N (0.40 mL, 2.94 mmol), and $B_2(OH)_4$ (263.5 mg, 2.94 mmol) in MeCN (2 mL) over 8 h at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with MeOH in CH_2Cl_2 gave compound **19** as a white solid; yield: 158 mg (90%); R_f (SiO_2/70% EtOAc in hexanes)= 0.33. IR (KBr): ν=3433, 1400, 785 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6+1 drop TFA-*d*): δ=15.90 (br s, NH, 1H), 8.75 (dd, J=1.2, 4.3 Hz, Ar-H, 1H), 8.47 (dd, J=1.0, 8.0 Hz, Ar-H, 1H), 7.54 (dd, J=4.4, 8.2 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop of TFA-*d*): δ= 151.4, 149.4, 131.2, 125.2, 121.1; HR-MS (ESI/TOF): m/z= 121.0524, calcd. for $C_5H_5N_4$ $[M+H]^+$: 121.0509.

6-Phenyl-1*H*-benzo[*d*][1,2,3]triazole (20): Synthesized using 6-phenyl-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.94 mmol), Et_3N (0.15 mL, 1.13 mmol), and $B_2(OH)_4$ (102 mg, 1.13 mmol) in MeCN (1.3 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **20** as a white solid; yield: 175 mg (95%); R_f SiO_2/50% EtOAc in hexanes)= 0.43. IR (KBr): ν=3435, 1209, 609 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ=15.78 (br s, NH, 1H), 8.14 (s, Ar-H, 1H), 8.02 (d, J=8.0 Hz, Ar-H, 1H), 7.78 (t, J=7.5 Hz, Ar-H, 3H), 7.53 (t, J=8.0 Hz, Ar-H, 2H), 7.43 (t, J=7.3 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop TFA-*d*): δ=140.5, 139.6, 138.9, 138.6, 129.3, 127.9, 127.7, 125.5, 115.8, 112.5; HR-MS (ESI/TOF): m/z=196.0872, calcd. for $C_{12}H_{10}N_3$ $[M+H]^+$: 196.0870.

6-(Naphthalen-1-yl)-1*H*-benzo[*d*][1,2,3]triazole (21): Synthesized using 6-(naphthalen-1-yl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.76 mmol), Et_3N (0.12 mL, 0.91 mmol), and $B_2(OH)_4$ (82.4 mg, 0.91 mmol) in MeCN (1 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **21** as a white solid; yield: 176 mg (94%); R_f (SiO_2/50% EtOAc in hexanes)=0.50. IR (KBr): ν=3467, 1203, 774 cm^{-1}. ^1H NMR (400 MHz, DMSO-d_6): δ=15.83 (br s, NH, 1H), 8.07–7.97 (m, Ar-H, 4H), 7.80 (d, J=8.4 Hz, Ar-H, 1H), 7.63–7.47 (m, Ar-H, 5H); ^{13}C NMR (100 MHz, DMSO-d_6): δ=138.9, 133.3, 130.9, 128.3, 127.8, 127.3, 126.4, 125.9, 125.5, 125.1; HR-MS (ESI/TOF): m/z=246.1030, calcd. for $C_{16}H_{12}N_3$ $[M+H]^+$: 246.1026.

6-(Thien-3-yl)-1*H*-benzo[*d*][1,2,3]triazole (22): Synthesized using 6-(thien-3-yl)-1*H*-benzo[*d*][1,2,3]triazol-1-ol (200 mg, 0.92 mmol), Et_3N (0.15 mL, 1.10 mmol), and $B_2(OH)_4$ (99.1 mg, 1.10 mmol) in MeCN (1.2 mL) over 30 min at 50 °C. Evaporation of the volatiles and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **22** as a white solid; yield: 166 mg (90%); R_f (SiO_2/50% EtOAc in hexanes)=0.41. IR (KBr): ν=3485, 1203, 780 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6+1 drop of TFA-*d*): δ=8.20 (s, Ar-H, 1H), 8.00 (s, Ar-H, 1H), 7.96 (d, J=8.5 Hz, Ar-H, 1H), 7.85 (d, J=8.8 Hz, Ar-H, 1H), 7.70–7.68 (m, Ar-H, 2H); ^{13}C NMR (100 MHz, DMSO-d_6+1 drop TFA-*d*): δ= 141.5, 139.3, 138.9, 133.4, 127.4, 126.8, 125.0, 121.9, 115.9, 111.4; HR-MS (ESI/TOF): m/z=202.0443, calcd. for $C_{10}H_8N_3S$ $[M+H]^+$: 202.0434.

General Procedure for C−C Cross-Coupling Reactions of 6-Bromo-1*H*-benzo[*d*][1,2,3]triazole with Arylboronic Acids

In a clean, dry 8-mL vial equipped with a stirring bar, 6-bromo-1*H*-benzo[*d*][1,2,3]triazole was dissolved in anhydrous 1,4-dioxane. The arylboronic acid and K_3PO_4 were

added, the mixture was sparged with argon gas, and then $PdCl_2$(dcpf) was added. The vial was capped and the mixture was stirred for 16 h at 100 °C. Upon completion of the reaction, the mixture was concentrated under reduced pressure, and the crude material was purified by chromatography on a silica gel column by gradient elution with 10–50% EtOAc in hexanes and in the case of compound **24** with 0–3% MeOH in CH_2Cl_2.

6-Phenyl-1*H*-benzo[*d*][1,2,3]triazole (20): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), phenylboronic acid (246 mg, 2.02 mmol), K_3PO_4 (428 mg, 12.32 mmol), and $PdCl_2$(dcpf) (152 mg, 0.202 mmol) in 1,4-dioxane (1.3 mL) over 16 h at 100 °C. Chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **20** as a pale brown solid; yield: 179 mg (90%).

6-(Naphthalen-1-yl)-1*H*-benzo[*d*][1,2,3]triazole (21): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), naphthalen-1-ylboronic acid (347 mg, 2.02 mmol), K_3PO_4 (428 mg, 12.32 mmol), and $PdCl_2$(dcpf) (152 mg, 0.202 mmol) in anhydrous 1,4-dioxane (1.3 mL) over 16 h at 100 °C. Chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **21** as a pale brown solid; yield: 195 mg (78%).

6-(Thien-3-yl)-1*H*-benzo[*d*][1,2,3]triazole (22): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), 3-thienylboronic acid (258 mg, 2.02 mmol), K_3PO_4 (428 mg, 12.32 mmol), and $PdCl_2$(dcpf) (152 mg, 0.202 mmol) in anhydrous 1,4-dioxane (1.3 mL) over 16 h at 100 °C. Chromatography of the crude material on a silica gel column by gradient elution with of EtOAc in hexanes gave compound **21** was obtained as a pale brown solid; yield: 180 mg (88%).

6-(4-Methoxyphenyl)-1*H*-benzo[*d*][1,2,3]triazole (23): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), *para*-methoxyphenylboronic acid (311 mg, 2.02 mmol), K_3PO_4 (428 mg, 12.32 mmol), and $PdCl_2$(dcpf) (152 mg, 0.202 mmol) in anhydrous 1,4-dioxane (1.3 mL) over 16 h at 100 °C. Chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **23** as a pale brown solid; yield: 172 mg (75%); R_f (SiO_2/50% EtOAc in hexanes) = 0.41. IR (KBr): ν = 3391, 1604, 808 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 8.06 (s, Ar-H, 1H), 7.98 (d, J = 8.5 Hz, Ar-H, 1H), 7.72 (d, J = 8.8 Hz, Ar-H, 3H), 7.08 (d, J = 8.5 Hz Ar-H, 2H), 3.85 (s, CH_3, 3H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 139.1, 138.7, 138.1, 132.5, 128.6, 125.5, 115.7, 114.6, 111.3, 55.2; HR-MS (ESI/TOF): m/z = 226.0981, calcd. for $C_{13}H_{12}N_3O$ $[M+H]^+$: 226.0975.

4-(1*H*-Benzo[*d*][1,2,3]triazol-6-yl)-3,5-dimethylisoxazole (24): Synthesized from 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), 3,5-dimethylisoxazol-4-ylboronic acid (283 mg, 2.02 mmol), K_3PO_4 (428 mg, 12.32 mmol), and $PdCl_2$(dcpf) (152 mg, 0.202 mmol) in anhydrous 1,4-dioxane (1.3 mL) over 16 h at 100 °C. Chromatography of the crude material on a silica gel column using gradient elution with MeOH in CH_2Cl_2 gave compound **24** as a pale brown solid; yield: 131 mg (60%); R_f (SiO_2/10% MeOH in CH_2Cl_2) = 0.41. IR (KBr): ν = 3468, 1634, 1195, 798 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 8.02 (d, J = 8.3 Hz, Ar-H, 1H), 7.93 (s, Ar-H, 1H), 7.46 (d, J = 8.0 Hz, Ar-H, 1H), 2.45 (s, CH_3, 3H), 2.27 (s, CH_3, 3H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 165.5, 139.3, 138.1, 127.4, 126.9, 116.0, 115.4, 115.2, 11.3, 10.4; HR-MS (ESI/TOF): m/z = 215.0939, calcd. for $C_{11}H_{11}N_4O$ $[M+H]^+$: 215.0928.

General Procedure for C–N Bond-Forming Reactions of 6-Bromo-1*H*-benzo[*d*][1,2,3]triazole with Arylamines

In a clean and dry 8-mL vial equipped with a stirring bar, 6-bromo-1*H*-benzo[*d*][1,2,3]triazole was dissolved in anhydrous 1,4-dioxane. The arylamine was added, the mixture was sparged with argon gas, and then *t*-BuONa, $Pd_2(dba)_3$, and $(t\text{-Bu})_3P$ were added. The vial was capped and the mixture was stirred for 6 h at 100 °C. Upon completion of the reaction, the mixture was diluted with CH_2Cl_2, filtered through Celite, and concentrated under reduced pressure. The crude material was purified by chromatography on a silica gel column by gradient elution with 10–50% EtOAc in hexanes and in the case of compound **29** with 0–5% MeOH in CH_2Cl_2.

***N*-(4-Methylphenyl)-1*H*-benzo[*d*][1,2,3]triazol-6-amine (25):** Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (150 mg, 0.76 mmol), *para*-toluidine (243 mg, 2.28 mmol), *t*-BuONa (73 mg, 1.52 mmol), $Pd_2(dba)_3$ (69.5 mg, 0.076 mmol), and $(t\text{-Bu})_3P$ (23.0 mg, 0.114 mmol) in anhydrous 1,4-dioxane (0.9 mL) over 6 h at 100 °C. Work-up of the reaction mixture and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **25** as a pale brown solid; yield: 135 mg (80%); R_f (SiO_2/50% EtOAc in hexanes) = 0.40. IR (KBr): ν = 3483, 3391, 1515, 808 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ = 15.05 (br s, NH, 1H), 7.81 (d, J = 8.9 Hz, Ar-H, 1H), 7.20 (d, J = 1.5 Hz, Ar-H, 1H), 7.14–7.09 (m, Ar-H, 5H), 2.24 (s, CH_3, 3H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop TFA-*d*): δ = 143.8, 140.0, 129.9, 129.6, 118.7, 116.8, 91.4, 20.3; HR-MS (ESI/TOF): m/z = 225.1142, calcd. for $C_{13}H_{13}N_4$ $[M+H]^+$; 225.1135.

***N*-(Naphthalen-1-yl)-1*H*-benzo[*d*][1,2,3]triazol-6-amine (26):** Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), naphthalen-1-amine (433 mg, 3.03 mmol), *t*-BuONa (193 mg, 2.02 mmol), $Pd_2(dba)_3$ (94.2 mg, 0.101 mmol), and $(t\text{-Bu})_3P$ (30.6 mg, 0.151 mmol) in 1,4-dioxane (1.0 mL) over 6 h at 100 °C. Work-up of the reaction mixture and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **26** as a pale brown solid; yield: 191 mg (72%); R_f (SiO_2/50% EtOAc in hexanes) = 0.42. IR (KBr): ν = 3478, 3390, 1521, and 791 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 8.17 (d, J = 7.6 Hz, Ar-H, 1H), 7.95 (d, J = 8.3 Hz, Ar-H, 1H), 7.86 (d, J = 8.9 Hz, Ar-H, 1H), 7.64 (d, J = 7.6 Hz, Ar-H, 1H), 7.56–7.44 (m, Ar-H, 4H), 7.27 (d, J = 8.9 Hz, Ar-H, 1H), 7.00 (d, J = 1.3 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 145.2, 138.7, 137.6, 136.3, 134.6, 128.3, 127.8, 126.2, 125.5, 123.0, 117.9, 1177.8, 116.8, 116.7, 94.1; HR-MS (ESI/TOF): m/z = 261.1148, calcd. for $C_{16}H_{13}N_4$ $[M+H]^+$: 261.1135.

***N*-(4-Methoxyphenyl)-1*H*-benzo[*d*][1,2,3]triazol-6-amine (27):** Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole

(150 mg, 0.76 mmol), *para*-anisidine (280 mg, 2.28 mmol), *t*-BuONa (73 mg, 1.52 mmol), $Pd_2(dba)_3$ (69.5 mg, 0.076 mmol), and $(t\text{-Bu})_3P$ (23.0 mg, 0.114 mmol) in 1,4-dioxane (0.85 mL) over 6 h at 100 °C. Work-up of the reaction mixture and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **27** as a pale brown solid; yield: 127 mg (70%); R_f (SiO_2/50% EtOAc in hexanes) = 0.31. IR (KBr): ν = 3467, 3391, 1510, 804 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6): δ = 14.92 (br s, NH, 1H), 8.18 (s, NH, 1H), 7.79 (s, Ar-H, 1H), 7.14–6.94 (m, Ar-H, 6H), 3.74 (s, CH_3, 3H); ^{13}C NMR (100 MHz, DMSO-d_6): δ = 154.5, 145.3, 138.9, 135.3, 134.5, 121.8, 119.1, 116.0, 114.6, 89.5, 55.2; HR-MS (ESI/TOF): m/z = 241.1086, calcd, for $C_{13}H_{13}N_4O$ $[M+H]^+$: 241.1084.

***N*-(1*H*-Benzo[*d*][1,2,3]triazol-6-yl)isoquinolin-5-amine (28):** Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (200 mg, 1.01 mmol), isoquinolin-5-amine (436 mg, 3.03 mmol), *t*-BuONa (193 mg, 2.02 mmol), $Pd_2(dba)_3$ (92.4 mg, 0.101 mmol), and $(t\text{-Bu})_3P$ (30 mg, 0.151 mmol) in anhydrous 1,4-dioxane (1 mL) over 6 h at 100 °C. Work-up of the reaction mixture and chromatography of the crude material on a silica gel column by gradient elution with EtOAc in hexanes gave compound **28** as a brown solid; yield: 178 mg (68%); R_f (SiO_2/10% MeOH in CH_2Cl_2) = 0.54. IR (KBr): ν = 3437, 3272, 1518, 1387, 824 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1drop TFA-*d*): δ = 9.91 (s, Ar-H, 1H), 8.73 (s, Ar-H, 2H), 8.12 (d, J = 7.8 Hz, Ar-H, 1H), 7.97–7.89 (m, Ar-H, 3H), 7.45 (s, Ar-H, 1H), 7.37 (d, J = 8.8 Hz, Ar-H, 1H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop TFA-*d*): δ = 147.5, 141.6, 140.3, 138.0, 137.3, 131.6, 131.1, 130.7, 128.6, 122.6, 121.2, 120.7, 119.5, 117.8, 99.7; HR-MS (ESI/TOF): m/z = 262.1099, calcd. for $C_{15}H_{12}N_5$ $[M+H]^+$: 262.1087.

4-(1*H*-Benzo[*d*][1,2,3]triazol-6-ylamino)benzonitrile (29): Synthesized using 6-bromo-1*H*-benzo[*d*][1,2,3]triazole (150 mg, 0.76 mmol), *para*-aminobenzonitrile (269 mg, 2.28 mmol), *t*-BuONa (73 mg, 1.52 mmol), $Pd_2(dba)_3$ (69.5 mg, 0.076 mmol), and $(t\text{-Bu})_3P$ (23 mg, 0.114 mmol) in anhydrous 1,4-dioxane (0.85 mL) over 6 h at 100 °C. Work-up of the reaction mixture and chromatography of the crude material on a silica gel column by gradient elution with MeOH in CH_2Cl_2 gave compound **29** as a pale brown solid; yield: 116 mg (65%); R_f (SiO_2/70% EtOAc in hexanes) = 0.40. IR (KBr): ν = 3436, 3338, 2212, 1606, 805 cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 7.94 (d, J = 8.7 Hz, Ar-H, 1H), 7.65 (d, J = 8.7 Hz, Ar-H, 2H), 7.56 (d, J = 1.5 Hz, Ar-H, 1H), 7.28 (dd, J = 1.8, 8.8 Hz, Ar-H, 1H), 7.22 (d, J = 8.8 Hz, Ar-H, 2H); ^{13}C NMR (100 MHz, DMSO-d_6 + 1 drop of TFA-*d*): δ = 148.1, 139.6, 137.9, 137.2, 133.8, 120.0, 119.9, 117.7, 115.2, 100.6, 100.2; HR-MS (ESI/TOF): m/z = 236.0933, calcd. for $C_{13}H_{10}N_5$ $[M+H]^+$: 236.0931.

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