PPh_3-Mediated Borylation of Arenediazonium Salts with Bis(pinacolato)diborane

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A metal-free, PPh_3-mediated borylation reaction of arenediazonium salts with bis(pinacolato)diborane has been developed under mild conditions. The process provides an attractive alternative to the traditional preparation of arylboronates, albeit in moderate yields.

Key words: Arenediazonium Salts, Borylation, Arylboronates

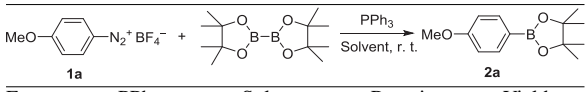
Introduction

Arylboronic acids or arylboronates are versatile building blocks in organic synthesis, which are extensively used in transition metal-catalyzed cross-coupling reactions [1 – 3]. The classical synthetic methods for the synthesis of organoboron coupounds are based on the reaction of trialkyl borates with Grignard or lithium reagents [4 – 6]. However, these reactions have major drawbacks, such as requiring rigorous anhydrous conditions and the limitation of substrates. In the past decades, numerous other useful methods have been developed. In 1995, the well-known Miyaura borylation, the palladium-catalyzed borylation of aromatic halides, provided a powerful method for the synthesis of aryl boronates [7]. This pioneering work spurred numerous investigations in the following years into the transition metal-catalyzed borylation of aromatic halides and pseudohalides [8 – 20]. Palladium and copper catalysts have been shown to be effective for the catalytic borylation. More recently, significant progress has also been made in selective borylation of C–H bonds of aromatic substrates by using rhodium and iridium complexes with B_2pin_2 or HBpin [B_2pin_2 = bis(pinacolato)diborane, Hpin = (pinacolato)hydridoborane] [21, 22]. In addition, palladium and ferrocene-catalyzed borylation reactions of arenediazonium salts using as coupling partners hasve been also developed by Andrus and Pucheault [23, 24]. Interestingly, Wang and co-workers in 2010 developed a novel metel-free method for the synthesis of arylboronates from arylamines with B_2pin_2 in the presence of *tert*-butyl nitrite [25]. This cost-effective procedure serves as an important complementary route to arylboronates. Although the mechanism of this reaction is not yet clear, the preliminary observations indicate that a radical process can be involved. More recently, Yan and co-workers reported a novel method for the synthesis of arylboronates through the borylation of arenediazonium salts catalyzed by Eosin Y under irradiation with visible light [26]. A radical mechanism has been proposed. As we know, arenediazonium salts are precursors of aryl radicals through a homolytic dediazoniation mechanism [27]. It has been demonstrated that PPh_3 transfers an electron to arenediazonium tetrafluoroborates to afford the arene radical and the cation radical of triphenylphosphine [28]. Herein, we report the borylation of arenediazonium salts with B_2pin_2 in presence of PPh_3 under mild conditions.

Results and Discussion

On the outset of this investigation, we used the arenediazonium salt **1a** as model substrate to screen suitable reaction conditions, and the results are summarized in Table 1. The borylation of **1a** in methanol (MeOH) indeed took place in the presence of PPh_3

Table 1. Optimization of the reaction conditions[a].



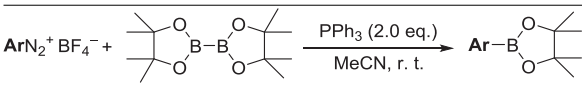
Entry	PPh_3 (equiv.)	Solvent	Reaction time (h)	Yield (%)[b]
1	1.5	MeOH	24	45
2	1.5	acetone	24	48
3	1.5	THF	24	43
4	1.5	MeCN	24	58
5	1.5	H_2O	36	15
6	1.5	MeCN-H_2O (5:1)	36	47
7	**2.0**	**MeCN**	**24**	**65**
8	1.0	MeCN	36	39
9	none	MeCN	36	trace

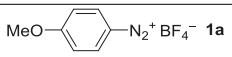
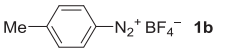
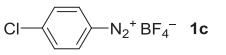
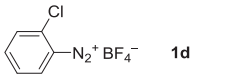
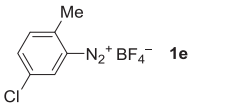
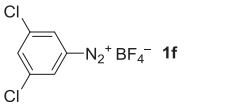
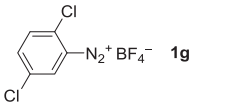
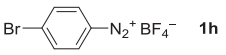
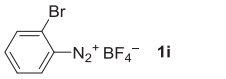
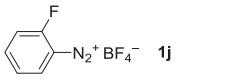
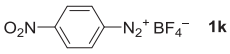
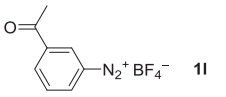
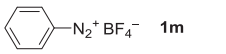
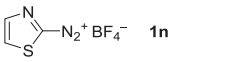
[a] The reaction conditions were as follows: **1a** (1.5 equiv.), B_2pin_2 (0.3 mmol), solvent (2 mL), at room temperature, under N_2; [b] isolated yield.

at room temperature, albeit in low yield (Table 1, entry 1). Encouraged by this initial result, we proceeded to optimize the proposed reaction conditions. Several other solvents were tested. Acetone and tetrahydrofuran (THF) afforded the borylation product with similar yields (Table 1, entries 2, 3). It was found that acetonitrile (MeCN) was the most suitable solvent to promote the reaction with 58 % yield (Table 1, entry 4), whereas the yield of the reaction dramatically dropped in water (Table 1, entry 5). Reaction with a mixed solvent of MeCN and water gave 47 % yield (Table 1, entry 6). We also found that the amount of PPh_3 had an important impact on the yield of the reaction. When 2.0 equivalents of PPh_3 were used, the yield of the reaction increased significantly (Table 1, entry 7). Finally, only a trace amount of **2a** could be detected by GC-MS, when the reaction was carried out in the absence of PPh_3(Table 1, entry 9).

Under the optimized conditions, the scope of acceptable substrates for this reaction was investigated. The results are summarized in Table 2. Arenediazonium salts having various electron-donating and electron-withdrawing groups preceded smoothly and afforded the corresponding borylation products in moderate to good yields. It has thus been observed that the reaction was only marginally affected by electronic effects of the substituents of arenediazonium salts. The arenediazonium salts bearing electron-deficient substituents (Table 2, entries 3, 6, 8, 11, 12) showed a slightly higher reactivity than those bearing electron-donating groups (Table 2, entries 1, 2). In addition, a substan-

Table 2. Substrate scope of PPh_3-mediated borylation of arenediazonium salts [a].



Entry	ArN_2^+ BF_4^- (**1a–n**)	Products (**2a–n**)	Reaction time (h)	Yield (%)[b]	Ref.
1		**2a**	24	65	[7]
2		**2b**	24	53	[25]
3		**2c**	18	67	[25]
4		**2d**	24	52	[26]
5		**2e**	18	58	[26]
6		**2f**	18	63	[26]
7		**2g**	24	57	[26]
8		**2h**	18	64	[25]
9		**2i**	24	48	[26]
10		**2j**	24	45	[26]
11		**2k**	18	65	[7]
12		**2l**	24	61	[25]
13		**2m**	24	48	[7]
14		**2n**	36	Trace	–

[a] The reaction conditions were as follows: **1a** (1.5 equiv.), B_2pin_2 (1.0 mmol), solvent (4 mL), at room temperature, under N_2; [b] isolated yield.

tial steric influence of the arenediazonium salts was obvious. For examples the reaction with *para*-chloro- or -bromo-substituted arenediazonium salts afforded higher yields than *ortho*-chloro- or -bromo-substituted arenediazonium salts (Table 2, entries 3, 4, 8, 9). It is particularly noteworthy that chloro, bromo and fluoro groups are tolerated in the reaction, which is advantageous for further transformations (Table 2, entries 3 – 10). The reaction also tolerated a wide range of other additional substituents, such as alkoxyl, alkyl, chloro, bromo, fluoro, nitro, and acetyl groups. However, the application of this process is problematic for the borylation of heteroaromatic diazonium salts (Table 2, entry 14). The reason for the failure of the reaction is less clear.

Conclusion

In conclusion, we have demonstrated the PPh_3-mediated borylation of arenediazonium tetrafluoroborate with B_2pin_2 under mild conditions. Further investigations of the detailed mechanism and the scope of substrates is currently underway in our laboratory.

Experimental Section

Triphenylphosphine, bis(pinacolato)diborane and arylamines were purchased from Alfa Aesar and Shaoyuan Webstore. [D]Chloroform was purchased from Cambridge Isotope Laboratories. All solvents were distilled prior to use. All reactions with air- and moisture-sensitive components were performed under a nitrogen atmosphere in a flame-dried reaction flask. For chromatography, 200 – 300 mesh silica gel (Qingdao, China) was employed. ^{1}H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra were measured on Bruker 300 M spectrometers. $CDCl_3$ was used as solvent with tetramethylsilane (TMS) as internal standard.

General procedure for the preparation of arenediazonium tetrafluoroborates

The arylamine (10 mmol) was dissolved in a mixture of 5 mL of distilled water and 3.4 mL of 50 % tetrafluoroboric acid. After cooling the reaction mixture to 0 °C in an ice bath, sodium nitrite (0.69 g in 2 mL of distilled water) was added dropwise within 5 min. The resulting mixture was stirred for 1 h, and the precipitate was collected by filtration and redissolved in the minimum amount of acetone. Diethyl ether was added until precipitation of the arenediazonium tetrafluoroborate, which was filtered, washed several times with diethyl ether, and dried under vacuum.

Typical procedure for the borylation of arenediazonium salts

An arenediazonium salt (1.5 mmol), bis(pinacolato)diborane (1 mmol) and PPh_3 (2.0 eq.) were weighed in a 25 L Schlenk round bottom flask under nitrogen atmosphere. Then 3 mL of acetonitrile was added by syringe. The resulting solution was stirred at room temperature. The reaction progress was monitored by GC-MS. After the completion of the reaction, the solution was filtered though a short column of silica gel and the column washed with ethyl acetate. The filtrate was concentrated under reduced pressure to leave a crude product, which was purified by flash column chromatography on silica gel to afford the final products.

Spectral data for the products

*2-(4-Methoxyphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2a**)* [7]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.81 (d, J = 9.0 Hz, 2H), 6.92 (d, J = 9.0 Hz, 2H), 3.83 (s, 3H), 1.36 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 162.2, 136.5, 113.3, 83.5, 55.0, 24.9 ppm.

*4,4,5,5-Tetramethyl-2-p-tolyl-1,3,2-dioxaborolane (**2b**)* [25]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.81 (d, J = 9.0 Hz, 2H), 7.27 (d, J = 9.0 Hz, 2H), 2.44 (s, 3H), 1.41 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 141.4, 134.9, 128.6, 83.6, 24.9, 21.8 ppm.

*2-(4-Chlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2c**)* [25]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.77 (d, J = 9.0 Hz, 2H), 7.37 (d, J= 9.0 Hz, 2H), 1.36 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.5, 136.2, 128.0, 84.0, 24.9 ppm.

*2-(2-Chlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2d**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.71 (d, J = 6.0 Hz, 1H), 7.47 ~ 7.24 (m, 3H), 1.39 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.0, 136.4, 131.8, 129.4, 125.8, 84.1, 24.8 ppm.

*2-(3-Chloro-5-methylphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2e**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.79 (d,J= 3.0 Hz, 1H), 7.32 ~ 7.28 (m, 1H), 7.12 (d, J = 9.0 Hz, 1H), 2.55 (s, 3H), 1.39 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.1, 135.4, 135.3, 131.3, 130.8, 130.6, 83.8, 24.9, 21.6 ppm.

*2-(3,5-Dichlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2f**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.65 (d, J = 3.0 Hz, 2H), 7.43 ~ 7.41 (m, 1H), 1.34 (s, 12H) ppm. – ^{13}C

NMR (75 MHz, $CDCl_3$): δ = 134.7, 132.7, 131.0, 84.5, 24.8 ppm.

*2-(2,5-Dichlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2g**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.67 (d, J = 3.0 Hz, 1H), 7.43 ~ 7.27 (m, 2H), 1.38 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.8, 136.1, 132.1, 131.7, 130.7, 84.5, 24.8 ppm.

*2-(4-Bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2h**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.69 (d, J = 9.0 Hz, 2H), 7.53 (d, J = 9.0 Hz, 2H), 1.35 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.3, 131.0, 126.2, 84.0, 24.9 ppm.

*2-(2-Bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2i**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.64 ~ 7.61 (m, 1H), 7.56 ~ 7.53 (m, 1H), 7.31 ~ 7.24 (m, 2H), 1.39 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.4, 132.6, 131.8, 128.0, 126.3, 84.3, 24.8 ppm.

*2-(2-Fluorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2j**)* [26]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.79 ~ 7.74 (m, 1H), 7.47 ~ 7.40 (m, 1H), 7.17 ~ 7.12 (t, J = 9.0 Hz, 1H), 7.07 ~ 7.01 (t, J = 9.0 Hz, 1H), 1.38 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.9, 165.5, 136.9, 136.8, 133.3, 133.2, 123.6, 123.5, 115.4, 115.1, 83.9, 83.8, 24.8 ppm.

*2-(4-Nitrophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2k**)* [7]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.18 (d, J = 9.0 Hz, 2H), 7.95 (d, J = 9.0 Hz, 2H), 1.36 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 149.8, 135.6, 122.3, 84.6, 24.8 ppm.

*1-(3-(4,4,5,5-Tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)ethanone (**2l**)* [25]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.29 (s, 1H), 7.99 ~ 7.90 (m, 2H), 7.38 (t, J = 6.0 Hz, 1H), 2.55 (s, 3H), 1.32 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 198.3, 139.3, 136.4, 134.7, 130.7, 127.9, 83.4, 24.9 ppm.

*2-Phenyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (**2m**)* [7]

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.94 ~ 7.90 (m, 1H), 7.84 (d, J = 6.0 Hz, 1H), 7.64 (d, J = 6.0 Hz, 1H), 7.50 ~ 7.28 (m, 2H), 1.37 (s, 12H) ppm. – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.6, 134.7, 131.2, 127.7, 127.1, 83.8, 24.9 ppm.

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