ORGANIC LETTERS
2012
Vol. 14, No. 13
3454–3457

Pd-Catalyzed Arylation of Chlorotrifluoroethylene Using Arylboronic Acids

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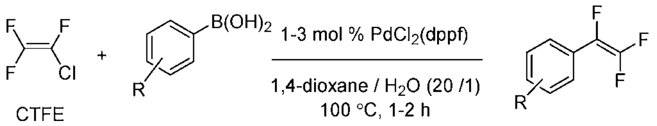
Received May 22, 2012

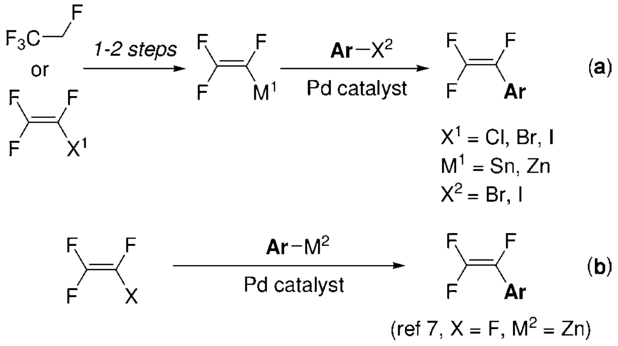
ABSTRACT



The palladium-catalyzed cross-coupling of chlorotrifluoroethylene and arylboronic acids proceeds in the presence of a base and H_2O to provide α,β,β-trifluorostyrene derivatives in satisfactory yields.

α,β,β-Trifluorostyrene derivatives are important intermediates for functional materials such as proton exchange membranes[1] and liquid crystals.[2] In the past three decades, several processes for α,β,β-trifluorostyrene derivative syntheses through the Pd-catalyzed cross-coupling of trifluorovinylzinc,[3] tin,[4] and boron[5] reagents with aryl halides have been developed (eq 1 in Scheme 1). Although these processes are superior to the classical ones in regards to the yields of the products,[6] the raw materials for the preparation of trifluorovinyl metal reagents are unsuitable for practical use: expensive and hazardous bromotrifluoroethylene for trifluorovinylzinc and tin and thermally unstable trifluorovinyllithium for trifluorovinylboron. Very recently, Ogoshi and co-workers succeeded in the

Scheme 1. Pd-Catalyzed Synthesis of α,β,β-Trifluorostyrene Derivatives



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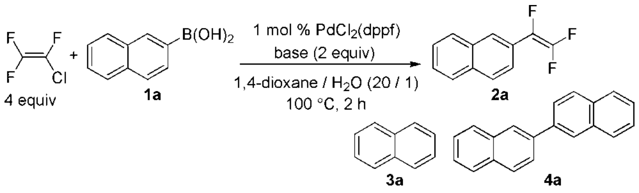
direct synthesis of α,*β*,*β*-trifluorostyrene derivatives by Pd-catalyzed cross-coupling using tetrafluoroethylene and arylzinc reagents (eq 2 in Scheme 1).[7] Their report is of significance from the academic and practical points of view, because (i) it discusses the first example of the catalytic transformation of tetrafluoroethylene through a carbon–fluorine bond and (ii) tetrafluoroethylene is economically viable feedstock. Chlorotrifluoroethylene (CTFE) is considered to be an alternative readily available raw material for α,*β*,*β*-trifluorostyrene derivative synthesis by Pd-catalyzed cross-coupling. Herein we reported the Pd-catalyzed coupling of CTFE and arylboronic acid to obatin α,*β*,*β*-trifluorostyrene derivatives.

When a mixture of CTFE, 2-naphthaleneboronic acid, $PdCl_2$(dppf), and Na_2CO_3 in 1,4-dioxane and H_2O were heated at 100 °C for 2 h, 2-(1,2,2-trifluorovinyl)-naphthalene was obtained in 78% isolated yield. Then, we examined the effect of the other base on this cross-coupling. The results are summarized in Table 1. When using K_2CO_3, the corresponding product **2a** was obtained in a good yield (entry 3), but Li_2CO_3 and Cs_2CO_3 were not effective for the reaction (entries 2 and 4). K_3PO_4 also afforded the product in a low yield (entry 5). While the use of NaF led to poor conversion of 2-naphthaleneboronic acid (entry 6), the reaction proceeded in good yields with other metal fluorides, KF and CsF (entries 7 and 8). Even though Na_2CO_3 exhibited the highest yield (entry 1), the yield reduced drastically in the absence of H_2O (entry 9). This is consistent with the general trend that the addition of water accelerates Pd-catalyzed Suzuki–Miyaura coupling.[8] The formation of **3a** can be explained by the protodeborylation that occasionally occurs in the Suzuki–Miyaura coupling.[9] On the other hand, the mechanism of **4a** formation probably through aryl scrambling[10] is now unclear. Since the suppression of these byproducts should bring about improvement of the yield of the desired product, further mechanistic investigation is necessary.

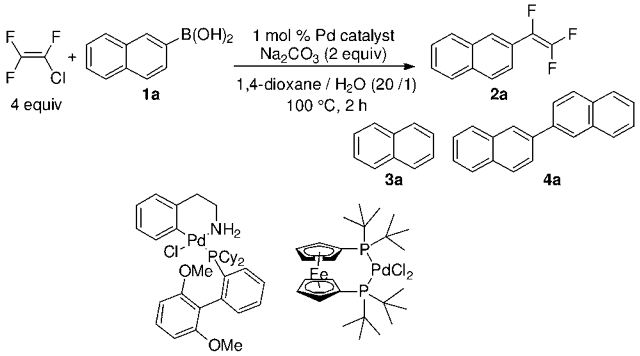
Table 1. $PdCl_2$(dppf)-Catalyzed Coupling of CTFE and 2-Naphthaleneboronic Acid[a]



entry	base	2a	3a	4a
		yield (%)[b]		
1	Na_2CO_3	84 (78)[c]	3	7
2	Li_2CO_3	32	1	2
3	K_2CO_3	71	3	11
4	Cs_2CO_3	39	18	19
5	K_3PO_4	56	8	9
6	NaF	6	1	2
7	KF	73	2	8
8	CsF	73	8	9
9[d]	Na_2CO_3	21	0	2

[a] The reaction was conducted with $PdCl_2$(dppf) (0.01 mmol), **1a** (1.0 mmol), CTFE (4 mmol), and base (2.0 mmol) in 1,4-dioxane (2.0 mL) and H_2O (0.1 mL) at 100 °C for 2 h. [b] Yields were determined by GC, based on the used amount of **1a**. [c] Isolated yield. [d] The reaction was carried out in the absence of H_2O.

Table 2. Pd-Catalyzed Coupling of CTFE and 2-Naphthaleneboronic Acid[a]



SPhos-palladacycle $PdCl_2$(d*t*Bpf)

entry	Pd catalyst	2a	3a	4a
		yield (%)[b]		
1	$PdCl_2$(dppf)	84	3	7
2[c]	$Pd(dba)_2$/dppf	76	1	4
3	$PdCl_2$(dppm)	62	4	9
4	$PdCl_2$(dppe)	76	1	6
5	$PdCl_2$(dppp)	74	3	8
6	$PdCl_2$(dppb)	82	3	4
7	$PdCl_2(PPh_3)_2$	67	2	10
8	$PdCl_2$(dtBpf)	23	5	26
9	$PdCl_2(PCy_3)_2$	59	1	15
10[d]	$Pd(dba)_2$/ $P(t\text{-}Bu)_3 \cdot HBF_4$	35	11	16
11	SPhos-palladacycle	20	2	6
12	$Pd(PPh_3)_4$	2	1	2

[a] The reaction was conducted with Pd catalyst (0.01 mmol), **1a** (1.0 mmol), CTFE (4 mmol), and Na_2CO_3 (2.0 mmol) in 1,4-dioxane (2.0 mL) and H_2O (0.1 mL) at 100 °C for 2 h. [b] Yields were determined by GC based on the used amount of **1a**. [c] [dppf]/[Pd] = 1.0. [d] $[P(t\text{-}Bu)_3 \cdot HBF_4]/[Pd] = 2.0$.

Next, we surveyed various palladium complexes, and the results are summarized in Table 2. Of the Pd complexes tested, $PdCl_2$(dppf) showed the highest activity (entry 1). The combination of $Pd(dba)_2$ and dppf also provided a satisfactory yield (entry 2). The diphenylphosphinoalkanes, which generally work as a bidentate ligand, provided the moderate yields (entries 3–6). In particular, the yield obtained when using $PdCl_2$(dppb) was virtually equal

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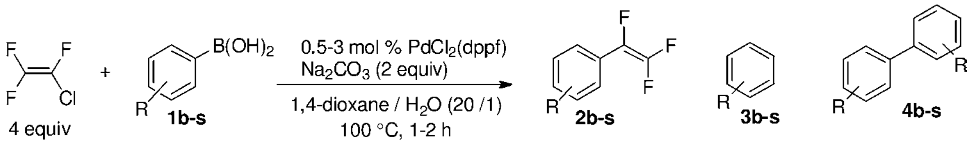
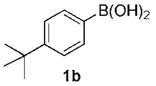
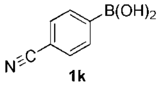
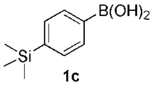
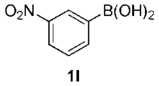
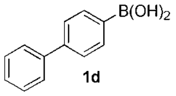
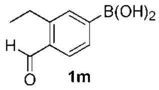
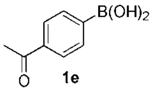
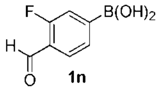
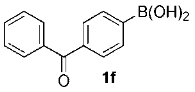
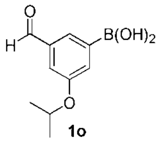
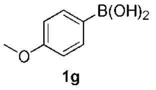
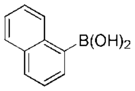
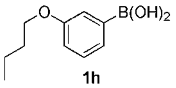
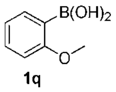
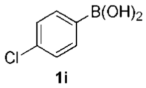
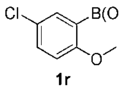
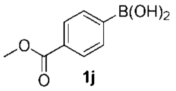
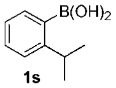
Table 3. Pd-Catalyzed Arylation of CTFE Using Arylboronic Acids[a]



entry	substrate	catalyst (mol %) / reaction time (h)	yield (%)			entry	substrate	catalyst (mol %) / reaction time (h)	yield (%)		
			2^b	3^c	4^c				2^b	3^c	4^c
1	 1b	1 / 2	87	1	4	10	 1k	2 / 2	65	1	2
2	 1c	1 / 2	84	1	3	11	 1l	1 / 2	80	6	3
3	 1d	1 / 2	79	2	na[d]	12	 1m	2 / 2	75	1	3
4	 1e	1 / 1	85	0	0	13	 1n	2 / 2	84	1	4
5	 1f	1 / 1	86	1	na[d]	14	 1o	2 / 2	86	2	4
6	 1g	0.5 / 2	71	3	6	15	 1p	1 / 2	75	5	5
7	 1h	0.5 / 2	70	2	2	16[e]	 1q	2 / 2	76	8	3
8	 1i	1 / 2	70	1	3	17	 1r	3 / 2	77	8	8
9	 1j	1 / 2	72	2	7	18	 1s	3 / 2	72	12	3

[a] The reaction was conducted with $PdCl_2(dppf)$ (0.005−0.03 mmol), arylboronic acid **1b**−**s** (1.0 mmol), CTFE (4 mmol), and Na_2CO_3 (2.0 mmol) in 1,4-dioxane (2.0 mL) and H_2O (0.1 mL) at 100 °C. [b] Isolated yield by silica gel column chromatography was determined based on the amounts of arylboronic acids **1b**−**s**. [c] Yields were determined by GC based on the used amounts of arylboronic acid **1b**−**s**. [d] Not analyzed. [e] The reaction was conducted at 120 °C.

to that obtained with $PdCl_2(dppf)$. $PdCl_2(PPh_3)_2$, the most readily available Pd(II)-phosphine complex, also gave a moderate yield (entry 7). In contrast, the alkylphosphines having a *tert*-butyl group or cyclohexyl group afforded the product in low yields (entries 8−11), indicating that the presence of phenyl groups on the phosphorus atom is advantageous for this coupling. Nevertheless, $Pd(PPh_3)_4$ exhibited a lower activity than $PdCl_2(PPh_3)_2$ (entry 12).

The scope of various arylboronic acids in this coupling is summarized in Table 3. The results obtained when using *para*- and *meta*-substituted arylboronic acids are shown in entries 1–14. The reactions with substrates having various functional groups such as alkyl, trialkylsilyl, phenyl, and acyl groups smoothly proceeded to give the corresponding products in excellent yields (entries 1–5). Alkoxy substituted arylboronic acids gave the products in good yields even when 0.5 mol % of the catalyst (entries 6 and 7) was used. The chloro atom on the phenyl ring was unaffected during the reaction. Preparation of arylzinc reagents having a nitro or formyl group for the Negishi coupling using tetrafluoroethylene ought to be difficult, because corresponding arylmagnesium reagents should be prepared.[7] In contrast, these groups can be tolerated in the synthesis of the corresponding arylboronic acids. Indeed, the substrates with nitro and formyl groups provided the desired products in good yields (entries 11–14). Sterically bulky arylboronic acids provided the corresponding products in good yields, although 2–3 mol % of catalyst were required (entries 16–18).

In conclusion, we demonstrated the Pd-catalyzed arylation of CTFE *via* the Suzuki–Miyaura coupling. The reaction gives ready access to various functionalized α,β,β-trifluorostyrene derivatives, regardless of the nature and position of functional groups. Further examinations of other functionalizations of CTFE and arylation of other fluorine-containing alkenyl halides[11] are underway in our laboratory.

Acknowledgment. We thank the Instrumental Analysis Laboratory, University of Toyama for the HRMS measurements. We are also grateful to Tosoh F-Tech Inc. for the generous gift of CTFE (chlorotrifluoroethylene). Technical assistance by Mr. Tomoyuki Morita (graduate student of Tokai University) is gratefully acknowledged.

Supporting Information Available. Experimental procedures and spectral data for isolated products. This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.

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