Carbostannylation of Alkynes Catalyzed by an Iminophosphine−Palladium Complex

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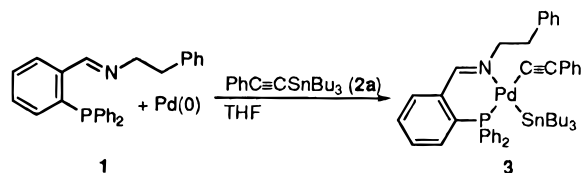*Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan*

Carbometalation of alkynes generates cis-substituted alkenyl-metals and is one of the most useful reactions for stereoselective olefin synthesis, since the resulting alkenylmetals can be transformed further to variously substituted ethylenes.[1] In particular, carbocupration,[2] zirconium-catalyzed carboalumination[3] and nickel-catalyzed carbozincation[4] have high synthetic potential due to wide applicability. Although alkenylstannanes are useful synthetic precursors for various olefinic targets,[5] no report has been published on the transition-metal-catalyzed carbostannylation of alkynes.[6−8] Here, we report the palladium-catalyzed carbostannylation of alkynes using alkynylstannanes.

We have already reported that tributyl(phenylethynyl)tin (**2a**) adds oxidatively to a palladium(0) complex coordinated by *N*-(2-(diphenylphosphino)benzylidene)-2-phenylethylamine (**1**) and that the resulting oxidative adduct (**3**) is involved in the catalytic cycle of the palladium-catalyzed coupling of **2a** with aryl iodides (Scheme 1).[9] We envisaged that palladium complex **3** should react with alkynes to give carbostannylation products. This turned out to be the case.

Treatment of **2a** with a 1:2 mixture of [PdCl(π-C₃H₅)]₂−**1** (5 mol % of Pd) under an acetylene atmosphere (1 atm) in THF at 50 °C for 2 h gave tributyl[(*Z*)-2-(phenylethynyl)ethenyl]tin (**5a**)[10] in 81% yield[11] as a single isomer through an exclusive syn-addition (Scheme 2). The use of triphenylphosphine (2 equiv to palladium) in place of **1** gave only 48% yield of **5a** in a prolonged period (43 h). A Pd(0)−1,3-bis(diphenylphosphino)propane
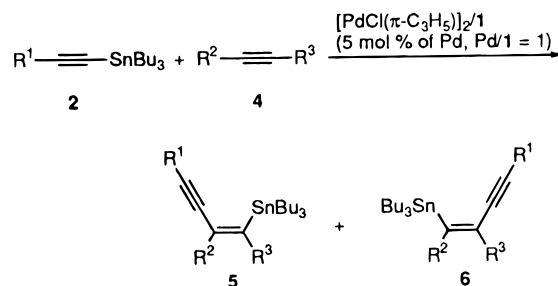
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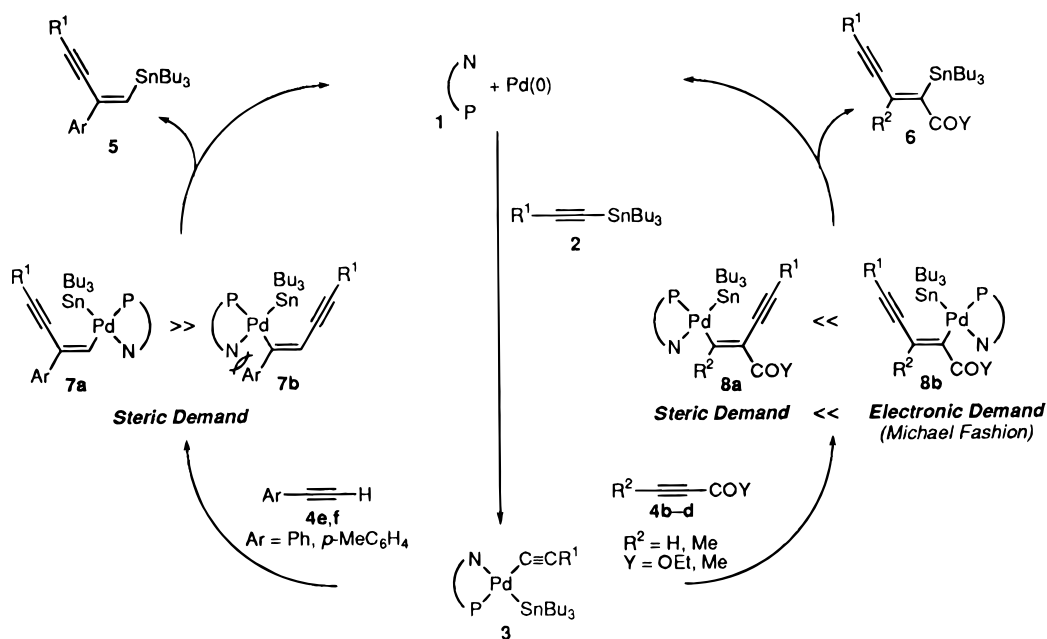
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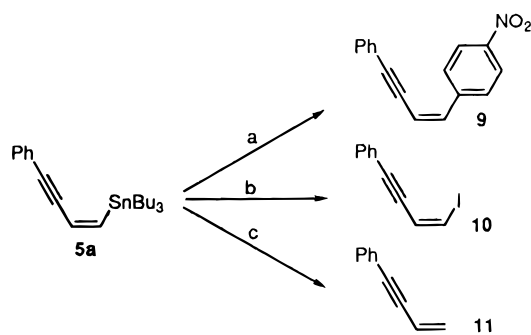
(10) Configuration of alkenylstannane **5a** could not be determined directly, because the olefinic protons of **5a** had the same chemical shift in ¹H NMR. The (*Z*)-configuration of **5a** was confirmed after the transformation to the corresponding alkenyl iodide (**10**) by iodolysis (Scheme 4). The coupling constant between olefinic protons of **10** was 8.3 Hz, which is typical to a cis-disubstituted ethylene. Iodolysis of α- or β-(alkynyl)alkenylstannanes to the corresponding (alkynyl)alkenyl iodides proceeds with retention of configuration: Stracker, E. C.; Zweifel, G. *Tetrahedron Lett.* **1991**, *32*, 3329−3332.

(11) The yield based on alkynylstannane should be lower than 95%, because 5% of alkynylstannane would be consumed for the reduction of Pd(II) to Pd-(0).

Scheme 1

Scheme 2

Table 1. Carbostannylation of Alkynes Catalyzed by Iminophosphine (**1**)−Palladium[a]

entry	R¹		R²	R³		temp (°C)	time (h)	yield (%)[b]	prod(s)	5/6[c]
1	Ph	(**2a**)	H	H	(**4a**)[d]	50	2	81	**5a**	
2	Ph	(**2a**)	CO₂Et	H	(**4b**)	50	3	78	**5b, 6b**	20/80
3	Ph	(**2a**)	CO₂Et	Me	(**4c**)[e]	90	90	57	**5c, 6c**	1/>99
4	Ph	(**2a**)	Ac	H	(**4d**)	50	4	76	**5d, 6d**	15/85
5	Ph	(**2a**)	Ph	H	(**4e**)	50	21	81	**5e, 6e**	92/8
6	Ph	(**2a**)	4-CH₃C₆H₄	H	(**4f**)	50	44	82	**5f, 6f**	91/9
7	Ph	(**2a**)	EtO	H	(**4g**)[f]	50	5	52	**5g, 6g**	>99/1
8	Bu	(**2b**)	H	H	(**4a**)[d]	50	4	66	**5h**	
9	Bu	(**2b**)	CO₂Et	H	(**4b**)	50	16	72	**5i, 6i**	12/88
10	Bu	(**2b**)	Ph	H	(**4e**)	50	29	80	**5j, 6j**	92/8

[a] The reaction was carried out in THF (5 mL) using an alkynylstannane (0.459 mmol) and an alkyne (1.38 mmol) in the presence of iminophosphine **1** (0.022 mmol) and [PdCl(π-C₃H₅)]₂ (0.011 mmol). [b] Isolated yield based on the alkynylstannane is given. [c] Determined by ¹H or ¹¹⁹Sn NMR. [d] The reaction was carried out under an acetylene atmosphere (1 atm). [e] Solvent = dioxane. [f] Ethoxyacetylene (0.459 mmol) was used.

complex, which also was shown to be added oxidatively by **2a**,[9] was much less effective to give **5a** in 28% yield even after 22 h.

The carbostannylation of various alkynes catalyzed by the Pd−**1** catalyst was next examined (Scheme 2, Table 1). The reaction of **2a** with ethyl propiolate (**4b**) gave carbostannylation products consisting of regioisomers **5b** and **6b** in a 20/80 ratio (entry 2). The carbostannylation of ethyl 2-butynoate (**4c**) resulted in higher regioselectivity, though higher temperature and longer reaction time were required (entry 3). A ketonic acetylene, 1-butyn-3-one (**4d**), reacted with **2a** smoothly with a regioselectivity similar to **4b** (entry 4). The reaction of arylacetylenes **4e** and **4f** with **2a** was relatively slow to give the corresponding carbostannylation products in high yields (entries 5 and 6) but with a reversed regioselectivity. The reaction of ethoxyacetylene (**4g**) also proceeded with high regioselectivity with the preference for **5g** over **6g** (entry 7). Tributyl(1-hexyn-1-yl)tin (**2b**) also reacted with alkyne **4a**, **4b**, or **4e**, giving the corresponding alkenylstannanes with the regioselectivity similar to **2a** (entries 8−10).[12]

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(12) No isomer other than **5** and **6** was obtained out of the four possible isomers in use of alkynes **4b**−**g**. The hydrolysis of the alkenylstannanes to the corresponding alkenes revealed that the stannyl group in **5** had a proton at the geminal position, whereas that in **6** had an R² group. Syn-addition in use of acetylene led us to the conclusion that both **5** and **6** are also syn.

Scheme 3

Scheme 4

(a) 4-O$_2$NC$_6$H$_4$I (0.92 equiv), Pd$_2$(dba)$_3$, (2-furyl)$_3$P (5 mol % of Pd, Pd/(2-furyl)$_3$P = 1/4), toluene, 90 °C, 13 h, 85% (based on 4-O$_2$NC$_6$H$_4$I). (b) I$_2$ (1.4 equiv), THF, 0 °C, 40 min, 91%. (c) conc. HCl, THF, rt, 1 h, 82%.

The catalytic cycle should first involve the oxidative addition of an alkynylstannane to the Pd(0) complex as discussed before.[9] Successive insertion of an alkyne to the C–Pd bond (carbopalladation)[13] of **3** followed by reductive elimination is likely to afford the carbostannylation product and regenerate the Pd(0) complex (Scheme 3). The opposite regioselectivity observed in use of arylacetylenes and alkynes having a carbonyl group can be explained by the followings. In the cases of arylacetylenes, carbopalladation giving alkenylpalladiums would prefer **7a** to **7b** by steric reason. Accordingly, alkenylstannanes **5** are afforded as main products. In contrast, electron-deficient alkynes **4b**, **4c**, and **4d** are likely to suffer the addition of the alkynyl group in a Michael fashion giving **6** predominantly through **8b**.

Finally, we confirmed the utility of the carbostannylation products by the transformation of carbostannylation product **5a** to various compounds (Scheme 4). The Pd–tri(2-furyl)phosphine-catalyzed coupling[14] of **5a** with 4-nitroiodobenzene gave enyne **9** in 85% yield.[15] Iodolysis or hydrolysis of **5a** afforded the corresponding alkenyl iodide (**10**) or enyne (**11**) in good yield, respectively.

In conclusion, we have demonstrated that the carbostannylation of alkynes takes place with alkynylstannanes to give conjugated (stannyl)enynes in a stereoselective manner. Studies on the details of the mechanism as well as synthetic applications to various unsaturated substrates and organostannanes are in progress in our laboratories.

Supporting Information Available: Detailed experimental procedures including spectroscopic and analytical data (5 pages, print/PDF). See any current masthead page for ordering information and Web access instructions.

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