Palladium-Catalyzed Bismetallative Cyclization of Enynes

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Summary: Enynes were reacted with $Me_3SiSnBu_3$ in the presence of Pd_2dba_3 CHCl₃ or $Pd(OH)_2$ on charcoal to give cyclized products containing a vinylsilane moiety and a homoallyltin moiety in good yield.

The addition of a bimetallic reagent to a multiple bond is of interest because new metal-carbon bonds are formed. It may be expected that further insertion of various multiple bonds into these metal-carbon bonds could occur. We have investigated the reactivity of compounds having an $Si-Sn^{1a}$ bond or an Si-Zr bond.^{1b} In this context, we investigated the palladium-catalyzed bismetallative cyclization of enynes with Me₃SiSnBu₃, **4**. If an enyne is treated with **4** in the presence of a palladium catalyst,² insertion of the alkyne part of **1** into the Si-Sn bond would be expected to occur to afford a cyclized compound, **2** or **2'**, which have Si-C and Sn-C bonds.³ Such products could be converted to various compounds using reactions of the metal-carbon bonds.

When a THF solution containing equimolar quantities of enyne **1a** and Me₃SiSnBu₃ was stirred at 50 °C in the presence of a catalytic amount of Pd(PPh₃)₄ for 4 h, a small amount of cyclized product **2a** was obtained (14% yield) along with a bismetalated derivative of the alkyne, **3a**, in 80% yield after the usual workup (Table 1, run 1). The ¹¹⁹Sn NMR spectra of **2a** and **3a** showed resonances at -15.7 and -53.2, respectively. Thus, **2a** contains an alkyltin moiety. An NOE experiment indicated that the *Z*-olefin had been formed (Scheme 2). To confirm the structure of **2a**, destannylation was carried out by treating it with HI in the presence of [Bu₄N]I at

(3) Bismetallative cyclization: See: (a) Obora, Y.; Tsuji, Y. Kakehi, T.; Kobayashi, M.; Shinkai, Y.; Ebihara, M.; Kawamura, T. *J. Chem. Soc., Perkin Trans.* 1 1995, 599. (b) Onozawa, S.-y.; Hatanaka, Y.; Tanaka, M. *Chem. Commun.* 1997, 1229. (c) Onozawa, S.-y.; Hatanaka, Y.; Choi, N.; Tanaka, M. *Organometallics* 1997, *16*, 5389. (d) Suginome, M.; Matsuda, T.; Ito, Y. *Organometallic* 1998, *17*, 5233. (e) Suginome, M. Ito, Y. *Chem. Rev.* 2000, *100*, 3221.

Scheme 1. Bismetallative Cyclization of Enyne



Scheme 2. Reaction of Enyne 1a with 4 in the Presence of Pd(0)



Table 1. Reaction of 1a with 4 in the Presence of
 $Pd(0)^a$

run	catalyst	solvent	time (h)	temp	yield (%)		
					2a	3a	1a
1	Pd(PPh ₃) ₄	THF	4	50 °C	14	80	
2	PdCl ₂ (PPh ₃) ₂	THF	6	reflux	7	48	
3	Pd(OAc) ₂ dppb	THF	5	reflux	20	34	
4	Pd(cod)Cl ₂	THF	16	rt	30		40
5	PdCl ₂ ^b	THF	45	rt	42		
6	$Pd_2(dba)_3$	THF	16	rt	63		
7	$Pd_2(dba)_3$	DMF	16	rt	10		15
8	$Pd_2(dba)_3$	toluene	16	rt	53		
9	Pd/C	THF	114	rt	86		10
10	$Pd(OH)_2/C^c$	THF	42	rt	88		5
11	$Pd(OH)_2/C^d$	THF	20	rt	90		2

^{*a*} All reactions were carried out using 3 mol % of Pd catalyst and 1.1 equiv of **4**. ^{*b*} 6 mol % of PdCl₂ and 1.5 equiv of **4** were used. ^{*c*} 6 mol % of Pd(OH)₂ on charcoal and 1.1 equiv of **4** were used. ^{*d*} 10 mol % of Pd(OH)₂ on charcoal and 1.5 equiv of **4** were used.

0 °C.⁴ A three-membered ring compound, **5a**, was obtained in good yield (Scheme 3). Probably, protonation occurs at the α -position of vinylsilane, and then the

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iodide anion attacks at the tin atom to close the threemembered ring.⁵ On the basis of these results, the structure of the cyclized compound is determined to be 2a, not 2a'.

The reaction was carried out under various conditions to improve the yield of the desired cyclized product **2a** (Table 1). It was found that the formation of the alkyne bismetalation product **3a** could be suppressed by using a palladium catalyst in the absence of a phosphine ligand (runs 1–6). THF was a suitable solvent, and toluene also can be used (runs 6–8). It is noteworthy that heterogeneous Pd catalysts, Pd/C or Pd(OH)₂/C,⁶ also afforded the desired product **2a** in high yield, although the reaction time was longer (runs 9–11).



Figure 1.

Various enynes, **1b**-**1h**, were reacted with Me₃-SiSnBu₃ in the presence of Pd₂dba₃·CHCl₃ (method A) or Pd(OH)₂/C (method B). The results are summarized in Table 2. In each case, the desired product **2** was obtained in moderate to good yield. The reaction of enyne **1e**, which has an electron-withdrawing substituent on the C=C bond, afforded the desired product **2e** in moderate yield, while the reaction of **1i** with a methyl

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Table 2. Bismetallative Cyclization of Enyne 1



Method A.: The reaction was carried out in the presence of $Pd_2 \cdot dba_3$ (3 mol %) and 1.1 equiv. of 4 at room temperature for 16 h. Method B: The reaction was carried out in the presence of 10 mol % of $Pd(OH)_2$ on charcol and 1.5 equiv. of 4 at room temperature.

substituent on the C=C bond (Figure 1) under similar conditions (method A) gave **2i**⁷ in only 7% yield. Bicyclic heterocycle **2g** or **2h** was produced stereospecifically from the corresponding enyne **1g** or **1h**, respectively.

However, in the reaction of **1g**, the alkyne bismetalation product **3g** was also obtained, which resulted in a lower yield of desired product **2g**. The reaction rate of enyne **1j** (Figure 1), which has a substituent on the alkyne, was relatively slow, and the cyclized product **2j** was obtained in only 5% yield. The starting material **1j** was recovered in 76% yield after 46 h (method A).

For the mechanism of this bismetallative cyclization, two possible pathways can be considered (Scheme 4). (1) The reaction proceeds by oxidative addition of Me₃-SiSnBu₃ to Pd(0) to give Me₃SiPdSnBu₃ (I)⁸ followed by insertion of the alkyne part of **1** into the Si–Pd bond to

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⁽⁷⁾ The cyclized product **2e** was obtained as a single diastereomer, whose stereochemistry has not been determined yet.



give complex II. Intramolecular insertion of the C=C bond into the C-Pd bond of II then occurs to give complex III, and reductive elimination finally affords

cyclized product **2** and Pd(0) is regenerated. (2) On the other hand, the possibility of the formation of IV^{3c} cannot be excluded in this mechanism. Thus, insertion of the C=C bond into the Sn-Pd bond in **II** could give complex **IV**. Reductive elimination from **IV** should afford the same cyclized product **2**. At present, it is not clear which pathway is followed in this reaction. Further studies are in progress.

Supporting Information Available: Typical procedure for bismetallative cyclization of enyne **1a**, spectral data for **2a**–**2h** and **5a**, and ¹H NMR spectrum of **2a–2h**. This material is available free of charge via the Internet at http://pubs.acs.org.

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(9) Very recently, Pd-catalyzed bismetallative cyclization of diynes with $Me_3SiSnBu_3$ has been reported, see: Gréau, S.; Radetich B.; RajanBabu, T. V. *J. Am. Chem. Soc.* **2000**, *122*, 8579.

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