Ni(0)-Catalyzed Bismetallative Cyclization of 1,3-Diene and a Tethered Aldehyde in the Presence of $Bu_3SnSiMe_3$

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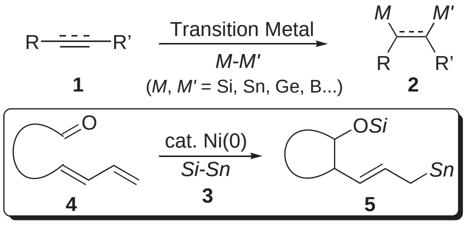
Ni(0)-Catalyzed bismetallative cyclization of 1,3-diene and a tethered aldehyde in the presence of $Me_3SiSnBu_3$ gave the corresponding cyclized product, having an allylstannyl group in the side chain, which could be used as an allylstannane in a coupling reaction with benzaldehyde.

Transition metal-catalyzed addition of a metal-metal σ-bond to carbon-carbon multiple bonds is an interesting reaction, since the resulting metal-containing compounds are useful reagents for organic syntheses. Although the intermolecular bismetallation of unsaturated organic molecules using a transition metal catalyst has been thoroughly investigated, there have been only several reports on intramolecular bismetallative cyclization.[1] Recently, we have reported a nickel-catalyzed stereoselective cyclization of 1,3-diene and tethered carbonyl groups in the presence of silane.[2] If $Bu_3SnSiMe_3$[3] is used in this cyclization of 1,3-diene and aldehyde instead of silane, a cyclized product **5** having an allylstannyl group would be produced, and this product could be used for a further carbon-carbon bond-forming reaction (Scheme 1).



Scheme 1.

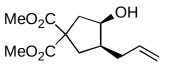
In order to examine the feasibility of bismetallative cyclization, we investigated a reaction of **4a** using $Bu_3SnSiMe_3$ (1.5 equiv) in the presence of $Ni(cod)_2$ (20 mol%) and a phosphine ligand (40 mol%) in toluene (Scheme 2).

Although $Ni(cod)_2$ and PPh_3, PCy_3, or $P(OEt)_3$ did not promote cyclization even under reflux conditions, the use of PMe_2Ph gave a cyclized product **5a** in 23% yield in a stereoselective manner (Table 1, run 1). Encouraged by this result, we examined the effects of a solvent using PMe_2Ph as a ligand. A cyclization of **4a** in THF provided **5a** and **6a** in a ratio of 1 to 21 in 43% yield (run 2). The reaction in a polar solvent gave good results (runs 3 and 4). Interestingly, this bismetallative cyclization in DMF proceeded even in the absence of a phosphine ligand, and only E-**5a** was obtained as the sole product (run 5), although the reason for this was not clear. When the resulting crude product, which was obtained from the reaction under the same conditions as those used in run 4, was treated with CF_3CO_2H, a protodestannylation product **7a** was obtained in 78% yield. This result suggests that the yield of cyclized product **5a** in this cyclization increased to 78% and that the product would be partially decomposed during purification.

Table 1. Ni(0)-Catalyzed bismetallative cyclization of **4a** with $Bu_3SnSiMe_3$ (3).

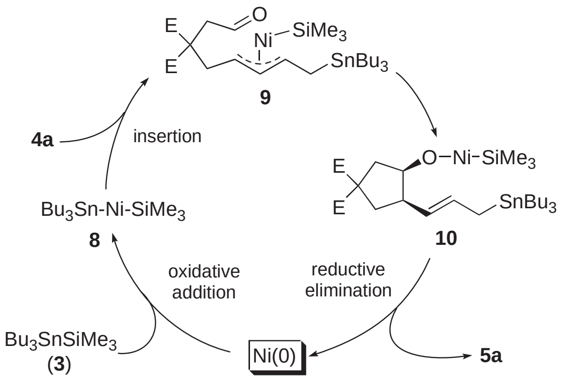
Run	Solvent	Time /h	Yield /% (**5**+**6**)	Ratio (**5**/**6**)	Ratio of *E*/*Z* **5**	Ratio of *E*/*Z* **6**
1	toluene	24	23	1 / >99		>99/1
2	THF	18	43	1 / 21	1.7/1	7.6/1
3	MeCN	4	46	2.5 / 1	3.8/1	2.5/1
4	DMF	2	66	1.5 / 1	3.6/1	3.4/1
5[a]	DMF	2	55	>99 / 1	>99/1	

[a] The reaction was carried out in the absence of PMe_2Ph.



7a

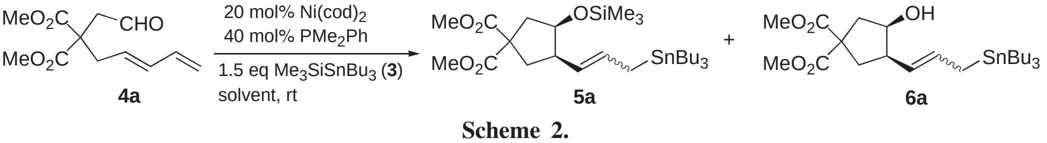
The possible reaction mechanism is shown in Scheme 3.



Scheme 3.

A silyl(stannyl)nickel complex **8** is formed by oxidative addition of $Me_3SiSnBu_3$ to a zerovalent nickel complex. The insertion of a Ni-Sn bond in **8** into the diene moiety in **4a** gives π-allylnickel intermediate **9**, which reacts with the tethered aldehyde group to give **10**. The reductive elimination from **10** affords the cyclized product **5a** accompanying regeneration of a zerovalent nickel complex.

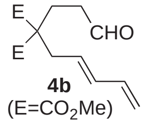
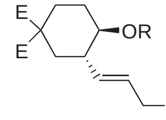
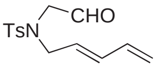
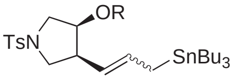
Next, cyclization of other substrates was examined (Table 2).



Scheme 2.

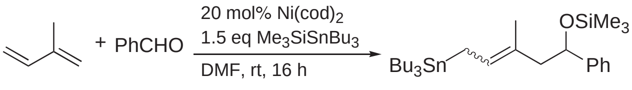
The cyclization of **4b** gave cyclohexane derivatives **5b** and **6b** (ratio of 1 to 7.5) in 51% yield (run 1). It was found that this bismetallative cyclization was applicable to construction of a pyrrolidine ring (run 2). Thus, the reaction of **4c** and $Bu_3SnSiMe_3$ in the presence of $Ni(cod)_2$ afforded pyrrolidine derivatives **5c** and **6c** in a ratio of 1 to 1.9 in 38% yield.[4]

Table 2. Silylstannylative cyclization using $Ni(cod)_2$ and PMe_2Ph.

Run[a]	Substrate	Time /h	Product Yield /%[b] (**5**+**6**)	Ratio (**5**/**6**)	Ratio of *E*/*Z* **5**	 **6**
1	 **4b** (E=CO_2Me)	5	51	1/7.5	*E* only	*E* only
			 **5b**:R=$SiMe_3$ **6b**:R=H			
2	 **4c**	2	38	1/1.9	3/1	2.4/1
			 **5c**:R=$SiMe_3$ **6c**:R=H			

[a]Both reactions were carried out in DMF at room temperature using $Ni(cod)_2$ (20 mol%), PMe_2Ph (40 mol%) and $Me_3SiSnBu_3$ (1.5 equiv). [b]Isolated yield.

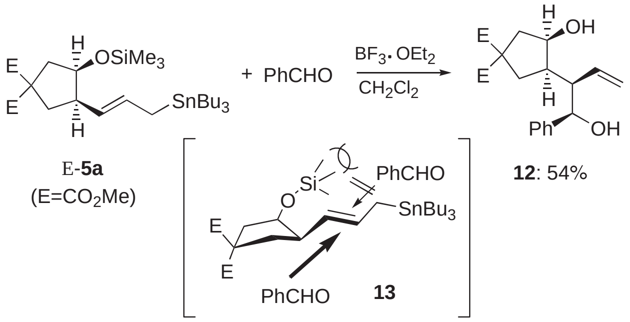
Next, we turned our attention to an intermolecular nickel-catalyzed three-component coupling reaction (Scheme 4). When a DMF solution of isoprene, benzaldehyde (1 equiv), $Me_3SiSnBu_3$ (1.5 equiv), and $Ni(cod)_2$ (20 mol%) was stirred at room temperature for 16 h, a coupling product **11** ($E/Z = 1.3/1$) was obtained in 49% yield.



11: 49% (*E*:*Z* = 1.3:1)

Scheme 4.

The products obtained by this bismetallative cyclization have an allylstannyl moiety, which could be used in further transformation. Thus, the cyclized product E-**5a** was reacted with benzaldehyde to give a coupling product **12** as the sole product in 54% yield (Scheme 5).



E-**5a** (E=CO_2Me)

12: 54%

13

Scheme 5.

The stereochemistry of **12** was tentatively assigned on the basis of the literatures[5] on a reaction of allylstannane and aldehyde in the presence of Lewis acid. It was also thought that benzaldehyde would attack allylstannane from the opposite side with a trimethylsilyloxy group as in **13** due to the steric bulk, which might have controlled the stereochemistry of **12**.

In conclusion, we succeeded in developing a novel bismetallative reaction of 1,3-dienes and aldehydes using a zerovalent nickel complex and $Bu_3SnSiMe_3$ as a bimetallic reagent to give a product having an allystannane moiety. In addition, we also succeeded in demonstrating the usefulness of this product in synthetic organic chemistry as an allylstannane compound. Further studies along this line, including a study on application to asymmetric synthesis, are in progress.

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This paper is dedicated to Professor Teruaki Mukaiyama on his 75th birthday.

References and Notes

1 For bismetallative cyclization, see: a) Y. Obora, Y. Tsuji, T. Kakehi, M. Kobayashi, Y. Shinkai, M. Ebihara, and T. Kawamura, *J. Chem. Soc.*, *Perkin Trans. 1*, **1995**, 599. b) S.-y. Onozawa, Y. Hatanaka, and M. Tanaka, *Chem. Commun.*, **1997**, 1229. c) S.-y. Onozawa, Y. Hatanaka, N. Choi, and M. Tanaka, *Organometallics*, **16**, 5389 (1997). d) M. Suginome, T. Matsuda, and Y. Ito,*Organometallics*, **17**, 5233 (1998). e) S. Gréau, B. Radetich, and T. V. RajanBabu, *J. Am. Chem. Soc.*, **122**, 8579 (2000). f) S.-K. Kang, T.-G. Baik, A. N. Kulak, Y.-H. Ha, Y. Lim, and J. Park, *J. Am. Chem. Soc.*, **122**, 11529 (2000). g) M. Mori, T. Hirose, H. Wakamatsu, N. Imakuni, and Y. Sato, *Organometallics*, **20**, 1907 (2001) h) S. Shin and T. V. RajanBabu, *J. Am. Chem. Soc.*, **123**, 8416 (2001).

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3 Recent reviews for transition metal-catalyzed addition of silylstannane to carbon-carbon multiple bonds, see: a) I. Beletskaya and C. Moberg, *Chem. Rev.*, **99**, 3435 (1999) and references cited therein. b) M. Suginome and Y. Ito, *Chem. Rev.*, **100**, 3221 (2000) and references cited therein.

4 In the cyclization of **4b** in the absence of PMe_2Ph, the cyclized product **5b** was produced in preference to the desilylated product **6b** (ratio **5b**/**6b** = 1.8/1) in total 31% yield. The cyclization of **4c** without PMe_2Ph gave (*E*)-**5c** in 18% yield as the sole product. These results are in accord with that shown in Table 1, run 5.

5 a) Y. Yamamoto, H. Yatagai, Y. Naruta, and K. Maruyama, *J. Am. Chem. Soc.*, **102**, 7107 (1980). b) Y. Yamamoto and N. Asao, *Chem. Rev.*, **93**, 2207 (1993) and references cited therein.