COMMUNICATION

ChemComm
www.rsc.org/chemcomm

# Synthesis of polycyclic compounds utilizing the nickel-catalysed alkynylstannylation of 1,2-dienes

**Eiji Shirakawa,*[a] Yoshiaki Nakao,[b] Teruhisa Tsuchimoto[a] and Tamejiro Hiyama*[b]**

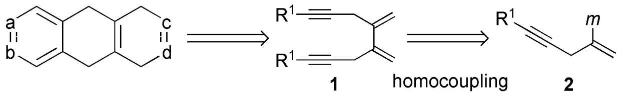
[a] *Graduate School of Materials Science, Japan Advanced Institute of Science and Technology, Asahidai, Tatsunokuchi, Ishikawa 923-1292, Japan. E-mail: shira@jaist.ac.jp*

[b] *Department of Material Chemistry, Graduate School of Engineering, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan. E-mail: thiyama@npc05.kuic.kyoto-u.ac.jp*

*Received (in Cambridge, UK) 28th June 2002, Accepted 24th July 2002*

**Polycyclic compounds having linearly-fused six-membered rings can be readily prepared by various modes of cyclization from dienediynes, which were synthesized through the nickel-catalysed alkynylstannylation of 1,2-dienes followed by the palladium-catalysed oxidative homocoupling of the resulting alkenylstannanes.**

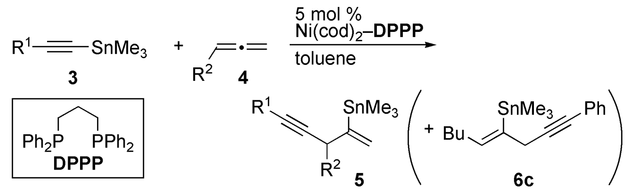
Polycyclic compounds having linearly-fused six-membered rings have acquired growing importance in the fields of functionality materials[1] and biologically active compounds.[2] Dienediynes **1** in Scheme 1 should be one of the most versatile precursors of polycyclic compounds, utilizing the diene and diyne moieties for cyclization with unsaturated compounds through cycloaddition reactions and transition metal-mediated reactions, respectively. Although homocoupling of α-(alkynylmethyl)vinylmetals **2** might readily afford **1**, there has been no convenient method available to synthesize alkenylmetals **2** having such a labile functional group as a carbon–carbon triple bond. On the other hand, we have disclosed that the palladium- or nickel-catalysed addition of organostannanes to alkynes gives vinylstannanes substituted with an alkynyl,[3] alkenyl,[4] allyl[3b,5] or acyl[3b] group, and have recently found that the acylstannylation of 1,2-dienes proceeds smoothly in the presence of a catalytic amount of a nickel complex to give α-(acylmethyl)vinylstannanes.[6,7] Herein we disclose that a nickel complex catalyses the alkynylstannylation of 1,2-dienes to give α-(alkynylmethyl)vinylstannanes, which are convertible into various polycyclic compounds *via* the palladium-catalysed oxidative homocoupling reaction.



Scheme 1

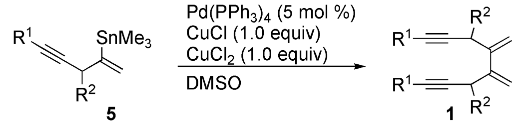
We first examined the addition of trimethyl(triethylsilylethynyl)tin (**3a**) with allene (**4a**) under conditions similar to those for the nickel-catalysed acylstannylation of allene (5 mol % of $Ni(cod)_2$, no ligand) to be disappointed by the formation of a complex mixture of products. Thorough investigation of the reaction conditions showed us that bisphosphines having a three-carbon linkage were crucial for the alkynylstannylation. For example, treatment of **3a** with 5 mol% of $Ni(cod)_2$–1,3-bis(diphenylphosphino)propane (**DPPP**) under an atmosphere of **4a** in toluene at 50 °C for 24 h gave 5-triethylsilyl-2-trimethylstannylpent-1-en-4-yne (**5a**) in 90% yield (Scheme 2).[8] The reaction of trimethyl(phenylethynyl)tin proceeded in a similar manner and alkenylstannane **5b** was obtained in 63% yield. The addition of carbon–tin bonds took place predominantly at the internal double bond of hepta-1,2-diene to give **5c** as the major product.

As expected, dienediynes **1** were readily obtained by the oxidative homocoupling of the alkynylstannylation products (Scheme 3). Thus, the palladium-catalysed reaction of **5** with a stoichiometric amount of CuCl–$CuCl_2$[9] afforded the corresponding dienediyne **1** in a good yield. The reaction of **5c** gave a mixture of *dl* and *meso* **1c** in an almost 1 : 1 ratio.



| $R^1$ | $R^2$ | temp | time | product | yield |
|---|---|---|---|---|---|
| $Et_3Si$ | H | 50 °C | 24 h | **5a** | 90% |
| Ph | H | 30 °C | 10 h | **5b** | 63% |
| Ph | Bu | 30 °C | 10 h | **5c** | 61% (Accompanied by 11% of **6c**) |

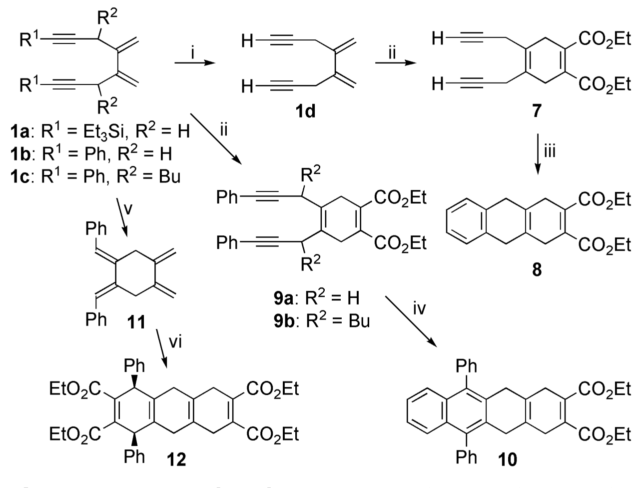
Scheme 2



| $R^1$ | $R^2$ | temp | time | product | yield |
|---|---|---|---|---|---|
| $Et_3Si$ | H (**5a**) | 40 °C | 0.8 h | **1a** | 73% |
| Ph | H (**5b**) | 50 °C | 2 h | **1b** | 86% |
| Ph | Bu (**5c**) | 50 °C | 3 h | **1c** | 82% (*dl*:*meso* = ca. 1:1) |

Scheme 3

The versatility of dienediynes **1** as synthetic precursors of polycyclic compounds is demonstrated in Scheme 4. For example, desilylation of **1a** with TBAF gave **1d**,[10] which underwent two different modes of cyclization, taking advantage of its conjugated diene and unconjugated diyne moieties. Thus,

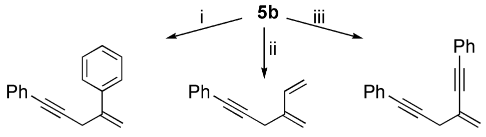


**Scheme 4** *Reagents and conditions*: i, $Bu_4NF$ (4.0 equiv.), AcOH (5.2 equiv.), THF, rt, 44 h, 92%; ii, $EtOCOC{\equiv}CCO_2Et$ (5.0 equiv.), toluene, 100 °C, 23 h, 100% (from **1d** to **7**); 28 h, 84% (from **1b** to **9a**); 37 h, 89% (from **1c** to **9b**); iii, $Ni(acac)_2$ (30 mol %), $(i\text{-}Bu)_2AlH$ (60 mol %), $PPh_3$ (1.2 equiv.), $HC{\equiv}CH$ (1 atm.), THF, rt, 21 h, 56%; iv, $Cp_2ZrBu_2$ (1.7 equiv.), THF, −78 °C, 1 h then rt, 1 h, then $o\text{-}I_2C_6H_4$ (3.0 equiv.), CuCl (3.9 equiv.), *N*,*N*′-dimethylpropyleneurea (5.1 equiv.), 50 °C, 15 h, 40%; v, $Cp_2ZrBu_2$ (2.0 equiv.), THF, −78 °C, 1 h then rt, 1 h, then CuCl (4.3 equiv.), *N*,*N*′-dimethylpropyleneurea (6.0 equiv.), rt, 2 h, 55%; vi, $EtOCOC{\equiv}CCO_2Et$ (8.0 equiv.), toluene, 100 °C, 28 h, 70%.

DOI: 10.1039/b206240b

annulation through the Diels–Alder reaction, followed by two-ring construction through nickel-catalysed reaction of the diyne moiety with acetylene, gave tricyclic compound **8**.[11] Similarly, Diels–Alder reaction of dienediyne **1b** and **1c** derived from a phenylethynylstannane gave **9a** and **9b**,[12] and **9a** was further converted into tetracyclic compound **10** through zirconocene-mediated reaction with *o*-diiodobenzene.[13] Alternatively, **1b** was first transformed by zirconocene-mediated cyclization to tetraene **11**, which underwent double Diels–Alder reaction with diethyl acetylenedicarboxylate to give tricyclic compound **12**.[14]

In addition to the homocoupling reaction, alkynylstannylation products can naturally be applied also to the palladium-catalysed cross-coupling reaction with various organic halides.[15] Actually, iodobenzene, vinyl bromide and 1-bromo-2-phenylethyne reacted with **5b** to give various alkynylmethyl substituted conjugated compounds (Scheme 5).



**13** **14** **15**

**Scheme 5** *Reagents and conditions*: i, Ph–I (1.0 equiv.), LiCl (1.5 equiv.), Pd(PPh$_3$)$_4$ (5 mol %), CuCl (1.0 equiv.), DMSO, 50 °C, 4.5 h, 87%; ii, CH$_2$ = CH–Br (3.0 equiv.), LiCl (1.5 equiv.), Pd$_2$(dba)$_3$ (2.6 mol %), CuCl (1.0 equiv.), DMSO–THF, 50 °C, 19 h, 47%; iii, Ph–C≡C–Br (1.3 equiv.), LiCl (1.5 equiv.), Pd(PPh$_3$)$_4$ (5 mol %), CuCl (1.0 equiv.), DMSO, 50 °C, 4 h, 83%.

In conclusion, we have demonstrated that dienediynes **1**, readily available from the alkynylstannylation products of 1,2-dienes, are versatile precursors for polycyclic compounds having linearly-fused six-membered rings. Further studies on details of synthetic applications are in progress in our laboratories.

E. S. thanks the Asahi Glass Foundation and the Ministry of Education, Sports, Culture, Science, and Technology, Japan Government, for Grant-in-Aid for Scientific Research, No. 12750758 for financial support. T. H. is thanking the Ministry of Education, Sports, Culture, Science, and Technology, Japan Government, for Grant-in-Aid for COE Research on Elements Science, No. 12CE2005.

## Notes and references

1 H. Hopf, *Classics in Hydrocarbon Chemistry*, Wiley-VCH, Weinheim, 2000, pp. 423–426.
2 K. Krohn, *Angew. Chem., Int. Ed. Engl.*, 1986, **25**, 790–807.
3 (*a*) E. Shirakawa, H. Yoshida, T. Kurahashi, Y. Nakao and T. Hiyama, *J. Am. Chem. Soc.*, 1998, **120**, 2975–2976; (*b*) E. Shirakawa, K. Yamasaki, H. Yoshida and T. Hiyama, *J. Am. Chem. Soc.*, 1999, **121**, 10221–10222; (*c*) H. Yoshida, E. Shirakawa, T. Kurahashi, Y. Nakao and T. Hiyama, *Organometallics*, 2000, **19**, 5671–5678.
4 E. Shirakawa, H. Yoshida, Y. Nakao and T. Hiyama, *J. Am. Chem. Soc.*, 1999, **121**, 4290–4291; H. Yoshida, E. Shirakawa, Y. Nakao, Y. Honda and T. Hiyama, *Bull. Chem. Soc. Jpn.*, 2001, **74**, 637–647.
5 E. Shirakawa, H. Yoshida, Y. Nakao and T. Hiyama, *Org. Lett.*, 2000, **2**, 2209–2211.
6 E. Shirakawa, Y. Nakao and T. Hiyama, *Chem. Commun.*, 2001, 263–264.
7 The palladium-catalysed three component coupling of 1,2-dienes, distannanes and organic iodides has been reported to give allylstannanes as net carbostannylation products of 1,2-dienes: F. Y. Yang, M. Y. Wu and C. H. Cheng, *Tetrahedron Lett.*, 1999, **40**, 6055–6058.
8 Although the reaction mechanism is not clear at present, it may follow the catalytic cycle of the acylstannylation of 1,2-dienes, which should start with oxidative addition of a carbon–tin bond to a nickel(0) complex. See reference 6.
9 (*a*) X. Han, B. M. Stoltz and E. J. Corey, *J. Am. Chem. Soc.*, 1999, **121**, 7600–7605; (*b*) E. Shirakawa, Y. Murota, Y. Nakao and T. Hiyama, *Synlett*, 1997, 1143–1144; (*c*) J. P. Parrish, V. L. Flanders, R. J. Floyd and K. W. Jung, *Tetrahedron Lett.*, 2001, **42**, 7729–7731, and references cited therein.
10 The synthesis of **1d** from 2,3-bis(bromomethyl)-1,3-butadiene and cyclization utilizing the diene moiety but not the diyne moiety has been reported: Y. Gaoni and S. Sadeh, *J. Org. Chem.*, 1980, **45**, 870–881.
11 Y. Sato, T. Nishimata and M. Mori, *J. Org. Chem.*, 1994, **59**, 6133–6135.
12 The homocoupling reaction of a mixture of *dl* and *meso* **1c** gave the corresponding diastereomeric mixture of **9b**.
13 T. Takahashi, R. Hara, Y. Nishihara and M. Kotora, *J. Am. Chem. Soc.*, 1996, **118**, 5154–5155.
14 The double Diels–Alder reaction of 1,2,4,5-tetramethylenecyclohexane has been reported: W. J. Bailey, E. J. Fetter and J. Economy, *J. Org. Chem.*, 1962, **27**, 3479–3482; D. T. Longone and F.-P. Boettcher, *J. Am. Chem. Soc.*, 1963, **85**, 3436–3443.
15 For a review of the palladium-catalysed coupling of organostannanes with organic electrophiles, see: K. Fugami and M. Kosugi, *Top. Curr. Chem.*, 2002, **219**, 87–130; Acceleration of the coupling reaction by cuprous chloride, see reference 9*a*.