Regio- and stereoselective hydrostannation of allenes using dibutyliodotin hydride (Bu_2SnIH) and successive coupling with aromatic halides†

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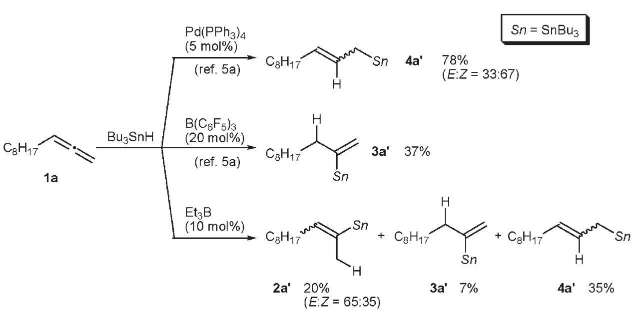
Regio- and stereoselective hydrostannation of allenes by using di-*n*-butyliodotin hydride (Bu_2SnIH) was accomplished to give α,β-disubstituted vinyltins, which induced the synthesis of multi-substituted alkenes in a one-pot procedure.

Vinyltin compounds are very useful reagents whose tin moieties can be transformed to various organic groups through the Kosugi–Migita–Stille coupling.[1] One of the most powerful synthetic methods for synthesis of vinyltins is hydrostannation of C–C triple bonds. Regioselective hydrostannation, however, is generally limited to terminal alkynes, in which the stannation occurred at the terminal carbon to give β-substituted vinyltins.[2] Few methods are available for synthesis of internal tin substituted adducts (α-substituted vinyltins), even when only monosubstituted vinyltins are obtained.[3] The effective synthesis of multi-substituted vinyltins remains to be a challenge.

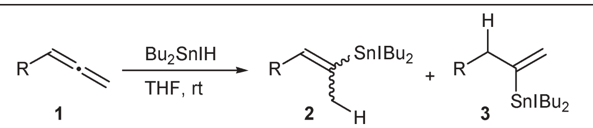
However, hydrostannation of allenes,[4] with a regioselectivity strongly dependent on the conditions employed, has rarely been reported (Scheme 1). In the hydrostannation of *n*-octylallene (**1a**), Pd-catalysis promotes the stannation of the terminal carbon to give allyltin **4a′**, and Lewis acid $B(C_6F_5)_3$ selectively produces an α-substituted terminal vinyltin **3a′**.[5] Only a radical reaction could produce an α,β-disubstituted vinyltin **2a′**, although a poor selectivity of **2a′** was obtained.[6] As illustrated in Scheme 1, it is accepted that no methods are available for the regio- and stereoselective addition of a tin moiety to the center carbon of allenes to give **2**. Here we wish to report the highly regio- and stereoselective radical hydrostannation of allenes which was accomplished by using di-*n*-butyliodotin hydride (Bu_2SnIH)[7] to give α,β-disubstituted vinyltins **2**. Furthermore, one-pot synthesis of multi-substituted alkenes was established by coupling of the resulting vinyltins without isolation.

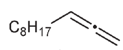
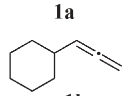
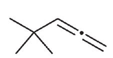
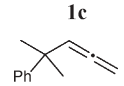
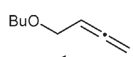
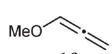


Scheme 1 Hydrostannation of allenes by Bu_3SnH.

First, hydrostannation of monosubstituted allenes was examined by using Bu_2SnIH generated *in situ* by the redistribution between Bu_2SnI_2 and Bu_2SnH_2.[8] The reaction of *n*-octylallene (**1a**) took place without any promoters to give vinyltin **2a** in 65% yield (Table 1, entry 1). This reaction plausibly proceeds in a radical manner because a radical scavenger, galvinoxyl, completely suppressed the reaction (entry 2). In contrast to tributyltin hydride, a predominant addition of a tin moiety to the allene center carbon took place in all runs to produce the α,β-disubstituted vinyltins **2** along with a small amount of **3**, and no formation of an allylic tin

Table 1 Hydrostannation of monosubstituted allenes[a]



Entry	Allene (**1**)	*t*/h	Product **2**: Yield (%) (*E* : *Z*)	**3**: Yield (%)
1	 **1a**	14	**2a**: 65 (58 : 42)	**3a**: 14
2[b]		14	Trace	Trace
3	 **1b**	17	**2b**: 88 (58 : 42)	**3b**: 9
4	 **1c**	20	**2c**: 70 (93 : 7)	**3c**: 9
5	 **1d**	44	**2d**: 70 (90 : 10)	**3d**: 2
6	 **1e**	33	**2e**: 59 (1 : >99)	**3e**: 13
7	 **1f**	21	**2f**: 57 (5 : 95)	**3f**: 2

[a] THF 1 mL, allene 1 mmol, Bu_2SnIH 1 mmol. [b] Galvinoxyl (0.1 mmol) was added.

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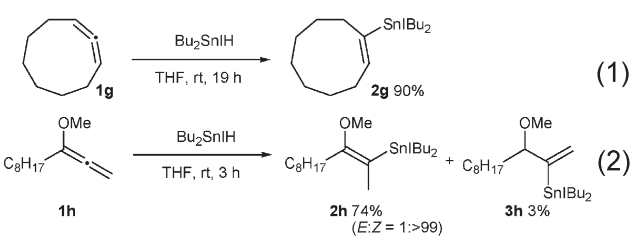
4 was observed. In the reaction of **1a**, using Bu_2SnClH instead of Bu_2SnIH resulted in a mixture of **2** (65%), **3** (17%) and **4** (11%). Although the hydrostannations of *n*- and *sec*-alkyl substituted allenes **1a** and **1b** furnished *E*- and *Z*-isomers of vinyltins **2a** and **2b** in poor stereoselectivities (entries 1 and 3), the selectivity was improved by introducing tertiary alkyl substituents to predominantly give *E*-alkenes (entries 4 and 5). It was surprising that the tertiary substituents also depressed the formation of vinyltin **3**, in particular the dimethylphenylmethyl moiety was decreased to only a 2% yield (entry 5). In contrast, allenes having oxygen substituents provided vinyltins **2e** and **2f** with opposite *Z*-stereochemistry (entries 6 and 7).

Scheme 2 shows the hydrostannation of disubstituted allenes. Cyclic vinyltin **2g** was obtained in 90% yield as a sole product from internal allene **1g** (eqn. (1)). 1,1-Disubstituted allene **1h**, having an oxygen substituent, gave trisubstituted vinyltin **2h** with perfect *Z*-stereochemistry (eqn. (2)).

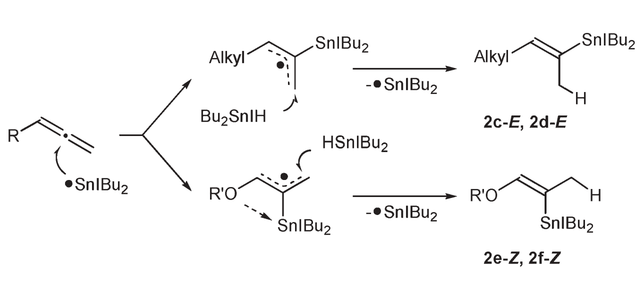
It has been reported that small amounts of the $Bu_2ISn^•$ radical is generated through the redistribution between Bu_2SnI_2 and Bu_2SnH_2, and so no radical initiator such as Et_3B is required.[8] As shown in Scheme 3, the generated tin radical is added to an allene carbon center to form a stable allyl radical, then a bulky Bu_2SnIH reacts with the less-hindered terminal carbon to produce the desired vinyltin **2**, along with regeneration of the $Bu_2ISn^•$ radical. However, the clear difference between having Bu_3SnH and having Bu_2SnIH in the attack position of a tin radical is yet to be explained. The *E*-stereoselectivity depends on steric repulsion between an alkyl substituent and the tin moiety in the formation of an allyl radical (Scheme 3, top). On the other hand, in the case of allenes with oxygen substituents, coordination with the acidic iodotin center helps form the *Z*-isomers, **2e** and **2f** (Scheme 3, bottom). Thus, the iodine-substituted tin moiety plays a very important role, having characteristics that are both sterically hindering and electron-withdrawing.

In the next stage, our group attempted to achieve a subsequent coupling reaction of the products **2** without isolation. The conventional catalyst for Kosugi–Migita–Stille coupling has not been feasible for use with halogenated organotin nucleophiles because of the deactivating nature of the halogen. If completed, however, this one-pot coupling would present a convenient method for synthesis of multi-substituted alkenes. Kosugi's group recently achieved this type of coupling between chlorinated aryltins and aryl halides.[9] Fortunately, our group was able to apply this catalysis on iodinated vinyltin **2** to produce various multi-substituted alkenes as shown in Scheme 4. Regio- and stereoselectivities of all products appeared to depend on the hydrostannation step. Thus *E*- and *Z*-alkenes, **5c** and **5f**, were obtained with high regio- and stereoselectivities (eqn (3) and (4)).‡ Internal allene **1g** gave trisubstituted alkene **5g** in moderate yield (eqn (5)). Tetrasubstituted alkenes, **5h–5j**, were also obtained from the reaction of allenes **1h**, **1i**, **1j** (eqn (6)–(8)). It is worth noting that alkenes bearing four different substituents, **5h** and **5j**, were produced with high stereoselectivities derived from chelation between the tin moiety and oxygen (eqn (6) and (8)). The stereochemistry obtained in **5j** suggests that the chelation is larger from the hydroxy moiety than it is that from the methoxy moiety.

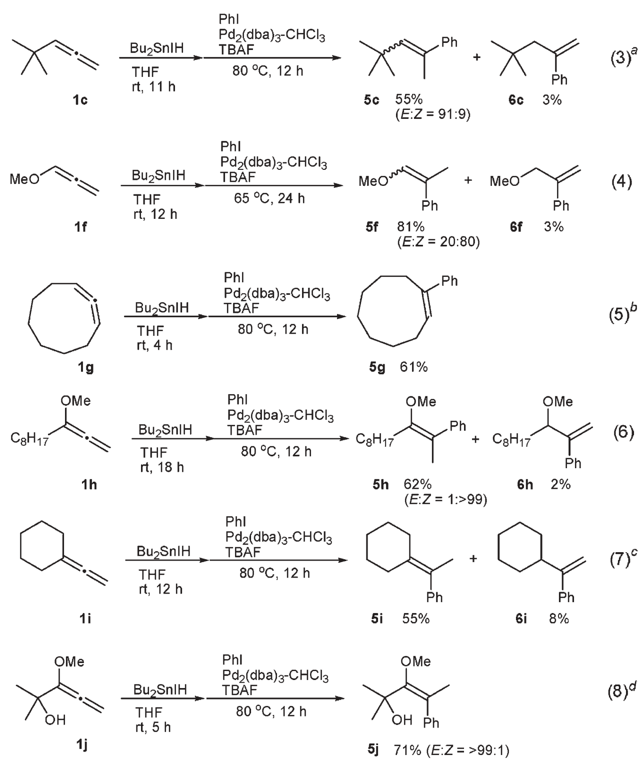
In summary, highly regio- and stereoselective hydrostannation of allenes was accomplished by using dibutyliodotin hydride (Bu_2SnIH). This system could also be applied to a subsequent coupling reaction to give multi-substituted alkenes in a one-pot procedure.



Scheme 2 Hydrostannation of disubstituted allenes. *Reagents*: THF (1 mL), allene (1 mmol), Bu_2SnIH (1 mmol).



Scheme 3 Regio- and stereoselective hydrostannation.



Scheme 4 Hydrostannation and one-pot coupling reactions. *Reagents*: THF (1 mL), allene (1 mmol), Bu_2SnIH (1 mmol), PhI (1 mmol), Pd cat. (0.01 mmol), TBAF (1 M solution in THF, 3.0 mmol). [a]Et_3B (0.1 mmol) was added at the hydrostannation step; PPh_3 (0.04 mmol) was added at the coupling step. [b]Bu_2SnIH (1.2 mmol) was used; Et_3B (0.1 mmol) was added at the hydrostannation step; PPh_3 (0.04 mmol) was added at the coupling step. [c]PPh_3 (0.07 mmol) was added at the coupling step. [d]PhI (1.2 mmol) was used.

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Notes and references

‡ *Typical experimental procedure to synthesize multisubstituted alkenes*: A 10 mL round-bottom flask was dried by flame under nitrogen atmosphere. After THF (1.0 mL) was added, Bu_2SnH_2 (0.117 g, 0.5 mmol) and Bu_2SnI_2 (0.243 g, 0.5 mmol) were added to generate Bu_2SnIH by the redistribution reaction. To the mixture was added allene **1f** (0.070 g, 1.0 mmol) and the resulting mixture was stirred at rt for 12 h until the IR absorption of Sn–H at 1855 cm^{-1} disappeared. [In the case of applying initiator, 1 M Et_3B solution (0.1 mL) was added after the addition of allenes.] PhI (0.204 g, 1.0 mmol), $Pd_2(dba)_3$–$CHCl_3$ (0.010 g, 1 mol%) and 1 M Bu_4NF solution in THF (3.0 mL) were added and the mixture was stirred at 65 °C for 24 h. After the reaction, the resulting solution was filtrated using Celite. After concentration of the filtrate, yield of product **5f** was determined by ^1H NMR (81%). Further purification was performed by silica gel column chromatography eluting with hexane–AcOEt = 95 : 5 followed by distillation under reduced pressure (0.070 g, 48%).

1 (*a*) R. F. Heck, in *Palladium Reagents in Organic Synthesis*, Academic, New York, 1985; (*b*) J. K. Stille, *Angew. Chem., Int. Ed. Engl.*, 1986, **25**, 508.

2 Recent reviews: (*a*) A. Baba, I. Shibata and M. Yasuda, in *Comprehensive Organometallic Chemistry III*, ed. R. H. Crabtree, D. Michael and P. Mingos, Elsevier, Oxford, 2006, **vol. 9**, ch. 8, pp. 341–380; (*b*) N. D. Smith, J. Mancuso and M. Lautens, *Chem. Rev.*, 2000, **100**, 3257; (*c*) A. G. Davis, *Organotin Chemistry*, VCH, New York, 1997, pp. 37–42; (*d*) M. Pereyre, J.-P. Quintard and A. Rahm, *Tin in Organic Synthesis*, Butterworth, London, 1987.

3 We have reported the addition of Bu_2SnIH-$MgBr_2$ ate complex, in which Bu_2SnIH by itself gave no products: (*a*) I. Shibata, T. Suwa, K. Ryu and A. Baba, *J. Am. Chem. Soc.*, 2001, **123**, 4101; Shirakawa has reported the hydrogenation of alkynyltins and successive rearrangement: (*b*) E. Shirakawa, R. Morita, T. Tsuchimoto and Y. Kawakami, *J. Am. Chem. Soc.*, 2004, **126**, 13614.

4 Preparation method of allenes: L. Brandsma and H. D. Verkruijsse, *Synthesis of Acetylenes, Allenes and Cumulenes*, Elsevier, Amsterdam, 1981.

5 (*a*) V. Gevorgyan, J.-X. Liu and Y. Yamamoto, *J. Org. Chem.*, 1997, **62**, 2963; (*b*) M. Lautens, D. Ostrovsky and B. Tao, *Tetrahedron Lett.*, 1997, **38**, 6343.

6 The reaction employing Ph_3SnH was reported to give 51% yield of α,β-disubstituted vinyltin **2**: Y. Ichinose, K. Oshima and K. Utimoto, *Bull. Chem. Soc. Jpn.*, 1988, **61**, 2693.

7 We have studied the reactivity of Bu_2SnIH: I. Shibata and A. Baba, *Curr. Org. Chem.*, 2002, **6**, 665.

8 A. G. Davies, W. J. Kinart and D. K. Osei-Kissi, *J. Organomet. Chem.*, 1994, **474**, C11.

9 K. Fugami, S. Ohnuma, M. Kameyama, T. Saotome and M. Kosugi, *Synlett*, 1999, 63.