Transfer of Alk-1-enyl Group from Boron to Tin: A Highly Stereoselective Synthesis of (*E*)-Alk-1-enyltributylstannanes

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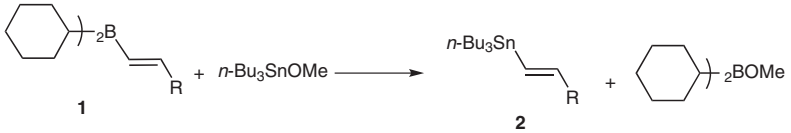
Abstract: Treatment of (*E*)-alk-1-enyldicyclohexylboranes with tributyltin methoxide in the presence of galvinoxyl (1 mol%) at room temperature results in transfer of the alk-1-enyl group from boron to tin to give (*E*)-alk-1-enyltributylstannanes in a highly stereoselective fashion. Subsequent halodestannylation of (*E*)-alk-1-enyltributylstannanes is allowed to proceed in a one-pot manner to produce the corresponding (*E*)-1-iodoalk-1-enes and (*E*)-1-bromoalk-1-enes in good to high yields, respectively.

Key words: transfer, (*E*)-alk-1-enyltributylstannane, (*E*)-alk-1-enyldicyclohexylborane, tributyltin methoxide, halodestannylation

Alkenylstannanes are valuable intermediates in organic synthesis, especially in Stille reaction.[1–7] Generally, alkenylstannnanes are prepared through hydrostannation of alkynes using radical initiators,[8–13] Lewis acid catalysts,[14–16] or transition metal catalysts.[17–22] Hydrostannation of alk-1-ynes via radical process induces isomerization of the product to give a mixture of stereoisomers, (*E*)- and (*Z*)-alk-1-enylstannanes, while the hydrostannation in the presence of a Lewis acid, such as $ZrCl_4$, proceeds with involving a certain pentacoordinated metal species derived from the acid to furnish (*Z*)-alk-1-enylstannanes stereoselectively. Transition-metal-catalyzed hydrostannation of alk-1-ynes usually occurs in a highly stereoselective fashion; however, the reaction gives a mixture of regioisomers, (*E*)-alk-1-enyl- and alk-2-enyl-stannanes. Alternatively, hydrostannation with dibutyliodotin hydride ate complex affords alk-2-enylstannanes with high product selectivities.[23] In preparation of alkenylstannnanes using stannylcupration of alk-1-ynes in place of hydrostannation, the regioselectivity depends on the nature of the stannylcopper species, the reaction temperature, and the structure of alk-1-yne, leading to either (*E*)-alk-1-enylstannane or alk-2-enylstannane predominantly.[24] Transmetalation of alkenyl metallic substrates, for example, aluminium[25–27] and copper,[28] is also a methodology for preparing alkenylstannanes. Quite recently, Williams et al. have reported transfer of (*Z*)-alk-1-enyl group from tellurium to tin via lithium.[29] We previously published that transfer of alkenyl group from boron to tin proceeded in the presence of a catalytic amount of copper compound and a stoichiometric amount of aqueous NaOH to result in formation of alkenylstannanes, including (*E*)- and (*Z*)-alk-1-enylstannanes with high stereoselectivities.[30,31] Although our method has the advantage of high regio- and stereoselectivities, the use of copper salt and aqueous NaOH would be undesirable for further synthetic elaboration in a one-pot manner. The development of a novel and useful procedure for preparing alkenylstannanes is thus still of importance. In continuation of our interest in transfer of alk-1-enyl group on boron,[32,33] herein, we report a simple and highly stereoselective synthesis of (*E*)-alk-1-enyltributylstannanes **2** via treatment of (*E*)-alk-1-enyldicyclohexylboranes **1** with tributyltin methoxide at room temperature (Scheme 1).

Initially, we attempted the reaction of (*E*)-hex-1-enyldicyclohexylborane (**1a**) with tributyltin methoxide and found that the reaction proceeded at room temperature to result in formation of (*E*)-hex-1-enyltributylstannane (**2a**),[34] observed by GC analysis. When further analyzed by ^{1}H NMR spectroscopy, the crude product was contaminated by a small amount of (*Z*)-hex-1-enyltributylstannane (**3a**).[35] Nevertheless, it is noteworthy that a simple reaction between **1a** and tributyltin methoxide caused transfer of hex-1-enyl group from boron to tin under mild conditions. On the other hand, it has been reported that the reaction of alkenyltributylstannanes with haloboron compounds such as BBr_3 and 9-bromo-9-BBN causes transfer of alkenyl group from tin to boron to form the corresponding alkenylboranes.[36,37] To easily determine the ratio of stereoisomers employing GC, we decided to uti-



Scheme 1 Transfer of (*E*)-alk-1-enyl group from boron to tin

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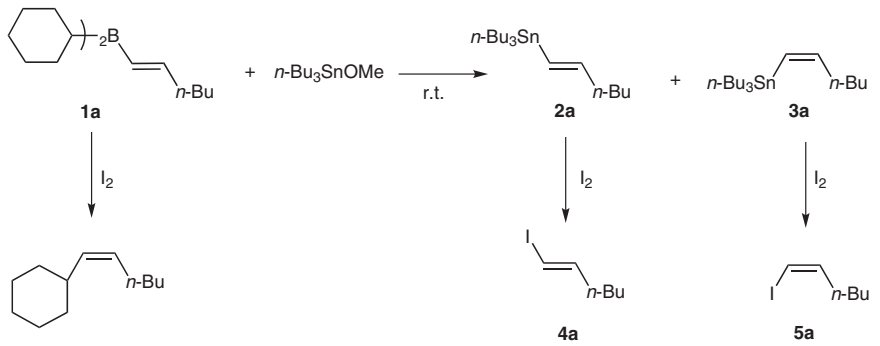
lize treatment of the reaction mixture with iodine (Scheme 2). Alkenylstannane undergoes iododestannylation to give iodoalkene with retention of configuration at the double bond,[38,39] whereas reaction of **1a** with iodine provokes a sequence of addition–migration–elimination reactions to form (*Z*)-1-cyclohexylhex-1-ene with high stereoselectivity.[40] Thus, the reaction of **1a** with tributyltin methoxide (1 equiv) was carried out at room temperature for 2 hours, followed by addition of a solution of iodine (1.1 equiv) in THF at –15 °C and stirring for 0.5 hours at 0 °C to give (*E*)-1-iodohex-1-ene (**4a**)[41] in 69% yield, along with (*Z*)-1-iodohex-1-ene (**5a**)[42] in 13% yield based on the starting amount of hex-1-yne. No formation of (*Z*)-1-cyclohexylhex-1-ene was observed. Despite our efforts to improve the stereoselectivity, a mixture of **4a** and **5a** was formed at all times. We assumed that a radical species might be generated during the reaction with tributyltin methoxide and give rise to isomerization of the product. If this is the case, then using a radical scavenger should prevent the reaction from generating radical species. This idea prompted us to examine the reaction of **1a** with tributyltin methoxide in the presence of galvinoxyl (0.01 equiv) as a radical scavenger. We were pleased to find that after iododestannylation **4a** was obtained as the sole product in 82% yield. Consequently, galvinoxyl not only could inhibit the formation of **3a** as expected, but also was free from interfering with transfer of (*E*)-hex-1-enyl group from boron to tin. Performing the reaction with tributyltin methoxide for 1 hour under otherwise identical conditions, the same result was obtained as described above.[43]

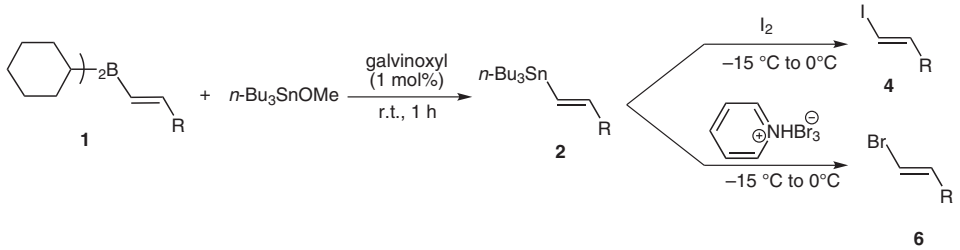
Bromodestannylation was also explored and, in consequence, pyridinium tribromide proved to be a suitable reagent. Thus, the reaction of (*E*)-oct-1-enyldicyclohexylborane (**1c**) with tributyltin methoxide was carried out in the presence of galvinoxyl (0.01 equiv) at room temperature for 1 hour, followed by addition of a solution of pyridinium tribromide (1.2 equiv) in THF under the same conditions as those described in iododestannylation to afford (*E*)-1-bromooct-1-ene (**6c**)[44] exclusively in 79% yield based on the starting amount of oct-1-yne (Scheme 3).

Encouraged by these initial results, we examined the scope of this reaction by conducting a survey of various alk-1-ynes. Table 1 shows the results of iodo- and bromodestannylation of (*E*)-alk-1-enyltributylstannanes **2** prepared via transfer reaction of (*E*)-alk-1-enyldicyclohexylboranes **1** derived from alk-1-ynes. The present reaction displays a broad substrate scope. For example, (*E*)-alk-1-enyldicyclohexylboranes **1** bearing bulky alkyl and phenyl groups as well as normal alkyl group participated in the transfer reaction. In addition, some functional groups were tolerated, including conjugated carbon–carbon double bond, chloro, and nitrile. The reaction of (*E*)-alk-1-enyldicyclohexylboranes **1** bearing phenyl derivatives with both electron-donating and electron-withdrawing substituents at the *para* position proceeded well to give the corresponding products, although (*E*)-2-(4-trifluoromethyl)phenyleth-1-enyldicyclohexylborane (**1i**) showed slightly lower yields. It should be noted that both (*E*)-1-iodoalk-1-enes **4** and (*E*)-1-bromoalk-1-enes **6** were provided in a highly stereoselective fashion and in good to high yields. Thus, these results indicated exclusive formation of (*E*)-alk-1-enyltributylstannanes **2**.

In summary, we have developed a highly stereoselective synthesis of (*E*)-alk-1-enyltributylstannanes **2** via transfer of (*E*)-alk-1-enyl group from boron to tin under neutral and mild reaction conditions. Furthermore, we have dem-



Scheme 2 Reaction of (*E*)-hex-1-enyldicyclohexylborane with tributyltin methoxide followed by treatment with iodine



Scheme 3 Synthesis of (*E*)-alk-1-enyltributylstannanes and subsequent iododestannylation or bromodestannylation

Table 1 Iodo- and Bromodestannylation of (*E*)-Alk-1-enyltributylstannanes **2** Derived from (*E*)-Alk-1-enyldicyclohexylboranes **1**[a]

R		Yield of product **4** (%)[b]	Yield of product **6** (%)[b]
n-Bu	**a**	82	
t-Bu	**b**	88	
n-C_6H_{13}	**c**		79
cyclohexenyl	**d**	86	88
$Cl(CH_2)_3$	**e**	78	75
$NC(CH_2)_3$	**f**	83	84
Ph	**g**	87	91
4-MeC_6H_4	**h**	78	88
4-$F_3CC_6H_4$	**i**	67	78

[a] Both iodo- and bromodestannylation were carried out at –15 °C to 0 °C using 1.1 equiv of iodine or 1.2 equiv of pyridinium tribromide.
[b] GC yields based on alk-1-yne employed.

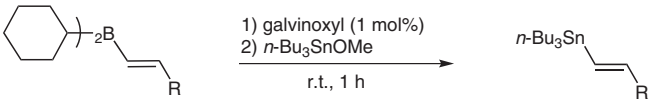
onstrated that the resulting (*E*)-alk-1-enyltributylstannanes **2** can undergo iodo- and bromodestannylation in a one-pot manner to provide the corresponding (*E*)-1-iodoalk-1-enes **4** and (*E*)-1-bromoalk-1-enes **6** in good to high yields, respectively. The synthetic advantages, including applicability to various substrates and compatibility to functional groups, would make it an alternative to currently available methods. Further synthetic applications of the resulting (*E*)-alk-1-enyltributylstannanes **2** are under way in our laboratory.

References and Notes

(1) Stille, J. K. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 508.
(2) Mitchell, T. N. *Synthesis* **1992**, 803.
(3) Davies, A. G. *Organotin Chemistry*; VCH: Weinheim, **1997**.
(4) Farina, V.; Krishnamurthy, V.; Scott, W. T. *Org. React.* **1998**, *50*, 1.
(5) Mitchell, T. N. In *Metal-Catalyzed Cross-Coupling Reactions*; Diederich, F.; Stang, P. J., Eds.; Wiley-VCH: Weinheim, **1998**, 167–202.
(6) Mitchell, T. N. In *Metal-Catalyzed Cross-Coupling Reactions*, Vol. 1; de Meijere, A.; Diederich, F., Eds.; Wiley-VCH: Weinheim, **2004**, 125–161.
(7) Abarbri, M.; Parrain, J.-L.; Duchene, A.; Thibonnet, J. *Synthesis* **2006**, 2951.
(8) Leusink, A. J.; Budding, H. A. *J. Organomet. Chem.* **1968**, *11*, 533.
(9) Nozaki, K.; Oshima, K.; Utimoto, K. *J. Am. Chem. Soc.* **1987**, *109*, 2547.
(10) Nakamura, E.; Imanishi, Y.; Machii, D. *J. Org. Chem.* **1994**, *59*, 8178.
(11) Miura, K.; Wang, D.; Matsumoto, Y.; Fujisawa, N.; Hosomi, A. *J. Org. Chem.* **2003**, *68*, 8730.
(12) Thiele, C. M.; Mitchell, T. N. *Eur. J. Org. Chem.* **2004**, 337.
(13) Miura, K.; Wang, D.; Hosomi, A. *Synlett* **2005**, 406.
(14) Asao, N.; Liu, J.-X.; Sudoh, T.; Yamamoto, Y. *J. Chem. Soc., Chem. Commun.* **1995**, 2405.
(15) Asao, N.; Liu, J.-X.; Sudoh, T.; Yamamoto, Y. *J. Org. Chem.* **1996**, *61*, 4568.
(16) Gevorgyan, V.; Liu, J.-X.; Yamamoto, Y. *Chem. Commun.* **1998**, 37.
(17) Smith, N. D.; Mancuso, J.; Lautens, M. *Chem. Rev.* **2000**, *100*, 3257.
(18) Trost, B. M.; Ball, Z. T. *Synthesis* **2005**, 853.
(19) Lin, H.; Kazmaier, U. *Eur. J. Org. Chem.* **2007**, 2839.
(20) Hamze, A.; Provot, O.; Brion, J.-D.; Alami, M. *J. Org. Chem.* **2007**, *72*, 3868.
(21) Darwish, A.; Lang, A.; Kim, T.; Chong, M. *Org. Lett.* **2008**, *10*, 861.
(22) Hamze, A.; Veau, D.; Provot, O.; Brion, J.-D.; Alami, M. *Org. Chem.* **2009**, *74*, 1337.
(23) Shibata, I.; Suwa, T.; Ryu, K.; Baba, A. *J. Am. Chem. Soc.* **2001**, *123*, 4101.
(24) Barbero, A.; Pulido, F. J. *Chem. Soc. Rev.* **2005**, *34*, 913.
(25) Corey, E. J.; Eckrich, T. M. *Tetrahedron Lett.* **1984**, *25*, 2415.
(26) Groh, B. L.; Kreager, A. F.; Schneider, J. B. *Synth. Commun.* **1991**, *21*, 2065.
(27) Groh, B. L. *Tetrahedron Lett.* **1991**, *32*, 7647.
(28) Corey, E. J.; Eckrich, T. M. *Tetrahedron Lett.* **1984**, *25*, 2419.
(29) Mirzayans, P. M.; Pouwer, R. H.; Williams, C. M. *Org. Lett.* **2008**, *10*, 3861.
(30) Hoshi, M.; Takahashi, K.; Arase, A. *Tetrahedron Lett.* **1997**, *38*, 8049.
(31) Hoshi, M.; Shirakawa, K.; Takeda, K. *Synlett* **2001**, 403.
(32) Hoshi, M.; Shirakawa, K.; Arase, A. *Chem. Commun.* **1998**, 1225.
(33) Hoshi, M.; Shirakawa, K. *Chem. Commun.* **2002**, 2146.
(34) The ^{1}H NMR spectrum of (*E*)-hex-1-enyltributylstannane(**2a**) shows the alkenyl protons at δ = 5.86 (d, *J* = 18.8 Hz) and 5.94 (dt, *J* = 18.8, 5.0 Hz) ppm.
(35) The ^{1}H NMR spectrum of (*Z*)-hex-1-enyltributylstannane(**3a**) exhibits the alkenyl protons at δ = 5.78 (dt, *J* = 12.4, 1.0 Hz) and 6.51 (dt, *J* = 12.4, 7.0 Hz) ppm.
(36) Singleton, D. A.; Martinez, J. P.; Ndip, G. M. *J. Org. Chem.* **1992**, *57*, 5768.
(37) Lee, U.-K.; Singleton, D. A. *J. Org. Chem.* **1997**, *62*, 2255.
(38) Ensley, H. E.; Buescher, R. R.; Lee, K. *J. Org. Chem.* **1982**, *47*, 404.
(39) Tolstikov, G. A.; Miftakhov, M. S.; Danilova, N. A.; Vel'der, Y. a. L. *Synthesis* **1986**, 496.
(40) Zweifel, G.; Arzoumanian, H.; Whitney, C. C. *J. Am. Chem. Soc.* **1967**, *89*, 3652.
(41) The ^{1}H NMR spectrum of (*E*)-1-iodohex-1-ene(**4a**) shows the alkenyl protons at δ = 5.97 (dt, *J* = 14.1, 1.0 Hz) and 6.51 (dt, *J* = 14.1, 7.3 Hz) ppm.
(42) The ^{1}H NMR spectrum of (*Z*)-1-iodohex-1-ene(**5a**) exhibits the alkenyl protons at δ = 6.14–6.19 (m)ppm.
(43) To a solution of BH_3·SMe_2 (1 mmol) in THF (3 mL) was added cyclohexene (0.164 g, 2 mmol) dropwise at 0 °C under argon, and the mixture was stirred for 2 h at this temperature to form a white suspension of dicyclohexylborane in THF. To this suspension was added hex-1-yne (0.082 g, 1 mmol) dropwise at 0 °C, and the mixture was stirred for 2 h at this temperature to produce a clear solution of (*E*)-hex-1-enyldicyclohexylborane(**1a**) in THF. To this solution was added galvinoxyl (0.004 g, 0.01 mmol) under a flow of argon, followed by dropwise addition of tributyltin methoxide (0.321 g, 1 mmol) at 0 °C. The resulting mixture was allowed to warm to r.t. and stirred for 1 h to generate (*E*)-hex-1-enyltributylstannane(**2a**). The solution of **2a**, thus prepared, was cooled to –15 °C, and a solution of I_2 (0.279 g, 1.1 mmol) in THF (1 mL) was added dropwise. The resulting mixture was allowed to warm to 0

°C and stirred for 0.5 h. The reaction mixture was treated with aq $Na_2O_3S_2$ to remove excess I_2, and then oxidized by the successive addition of 3 M NaOH (1 mL) and 30% H_2O_2 (0.5 mL) at 0 °C. After being stirred for 1 h at this temperature, the mixture was extracted three times with Et_2O. The combined extracts were washed with brine and a 10% aq solution of KF, dried over Na_2SO_4, and concentrated. The residue was purified by column chromatography on silica gel, with pentane as eluent, to give (*E*)-1-iodohex-1-ene (**4a**, 0.151 g, 72%).

(44) (*E*)-Oct-1-enyltributylstannane(**2c**) was prepared in the same manner as described in ref. 41 but using oct-1-yne (0.110 g, 1 mmol) instead of hex-1-yne. To the solution of **2c** in THF was added a solution of pyridinium tribromide (0.384 g, 1.2 mmol) in THF (2 mL) dropwise at –15 °C, and the mixture was allowed to warm to 0 °C and stirred for 0.5 h. The workup procedure was the same as described in ref. 41, except for washing with aq $Na_2O_3S_2$. Elution with pentane gave (*E*)-1-bromooct-1-ene (**6c**, 0.134 g, 70%). The ^{1}H NMR spectrum of **6c** shows the alkenyl protons at δ = 6.01 (d, *J* = 13.4 Hz) and 6.15 (dt, *J* = 13.4, 6.4 Hz) ppm.



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