Hydroxy Group-Directed Homolytic Hydrostannylation of Alkenols with Dibutylchlorostannane

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In homolytic hydrostannylation of allyl alcohol **1a** or homoallyl alcohol **1b**, dibutylchlorostannane (Bu_2ClSnH) exhibited a much higher reactivity than tributylstannane (Bu_3SnH). Competitive reaction of **1a** *vs.* 1-octene with Bu_2ClSnH led to the selective formation of γ-stannylated alcohol **3a**. Hydrostannylation of 1,5-hexadien-3-ol (**8**) with Bu_2ClSnH favored 1-stannylated product **9** over 6-stannylated product **10**, while the use of Bu_3SnH decreased the regioselectivity.

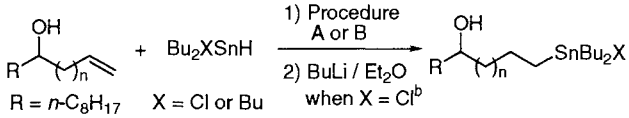
In recent years, it has been widely recognized that the use of Lewis acids is effective in improving stereoselectivity and efficiency in radical reactions.[1] The functions of Lewis acids in these processes are similar to those shown in ionic reactions. The complexation of a Lewis acid fixes the conformation of a substrate bearing a polar functional group to control the reaction site. In addition, Lewis acids accelerate radical reactions by enhancing the electophilicity of the radical intermediates or their acceptors.

Hydrostannylation of alkenes and alkynes with hydrostannanes is a most efficient method for introduction of a stannyl group.[2] It is well known that this process has been achieved under radical conditions.[3] In the course of our study on the radical reaction of organotin compounds,[4] it occurred to us that homolytic hydrostannylation of a dialkylhalostannane (R_2XSnH) to alkenes and alkynes could be directed by the tin-centered Lewis acidity of intermediate radicals arising from R_2XSnH, which itself is a Lewis acid.[5,6] Numerous papers concerned with Lewis acid-mediated radical reactions have been reported;[1] however, the reaction controlled by a Lewis acid derived from a radical precursor is unprecedented except one recent report.[5] We now demonstrate that Bu_2ClSnH exhibits high reactivity toward the homolytic hydrostannylation of allyl and homoallyl alcohols.[7]

We first examined the hydrostannylation of allyl alcohol **1a** with Bu_2ClSnH and Bu_3SnH to clarify the difference between the two hydrostannanes in reactivity. For this purpose, two different procedures, A and B, were employed. In procedure A, the reaction was induced by Et_3B-O_2 in hexane at rt,[8] while in procedure B, the AIBN-initiated reaction was performed without a solvent at 60 °C.[9] Bu_2ClSnH was in advance prepared from Bu_2SnCl_2 and Bu_2SnH_2 for each reaction (rt, 5 min).[10] The Bu_2ClSnH adduct **2a**, which could be identified by the ^1H NMR analysis, was converted to **3a** by treatment with BuLi in Et_2O to facilitate the isolation of the hydrostannylated product by column chromatography. As shown in Table 1, Lewis acidic Bu_2ClSnH exhibited much higher reactivity toward **1a** than Bu_3SnH, irrespective of the employed procedure (runs 1-4). The hydrostannylation of homoallyl alcohol **1b** gave similar results (runs 5 and 6).

Competitive hydrostannylation of **1a** *vs.* 1-octene with Bu_2ClSnH afforded γ-stannylated alcohol **3a**, exclusively (Eq. 1). In contrast, the competitive reaction with Bu_3SnH resulted in much less selectivity. These results imply that the interaction between the hydroxy group and the Lewis acidic tin center accelerates the hydrostannylation of **1a** with Bu_2ClSnH.

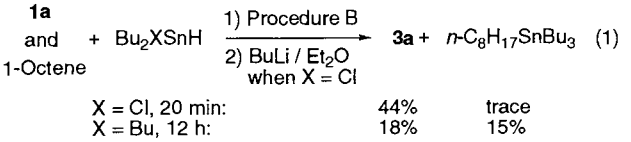
Table 1. Hydrostannylation of Alkenols **1a** and **1b**[a]



R = *n*-C_8H_{17}
1a: n = 0
1b: n = 1
2a: X = Cl, n = 0; **3a**: X = Bu, n = 0
2b: X = Cl, n = 1; **3b**: X = Bu, n = 1

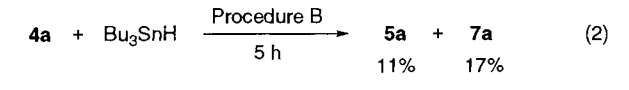
Run	Substrate	Bu_2XSnH X	Procedure[a]	Time	Yield of **3**/%
1	**1a**	Cl	A	14 h	83
2	**1a**	Cl	B	15 min	83
3	**1a**	Bu	A	4 d	5
4	**1a**	Bu	B	15 h	44
5	**1b**	Cl	B	1 h	87
6	**1b**	Bu	B	1 d	11

[a]All reactions were carried out with alkenol (1.0 mmol) and hydrostannane (1.2 mmol) under N_2. Procedure A: Et_3B (0.1 mmol), air (10 mL), and hexane (2 mL) at rt. Procedure B: AIBN (0.1 mmol) at 60 °C. [b]When X = Cl, the crude product was treated with BuLi (4.0 mmol) in Et_2O (5 mL) at -78 °C for 4 h.



X = Cl, 20 min: 44% trace
X = Bu, 12 h: 18% 15%

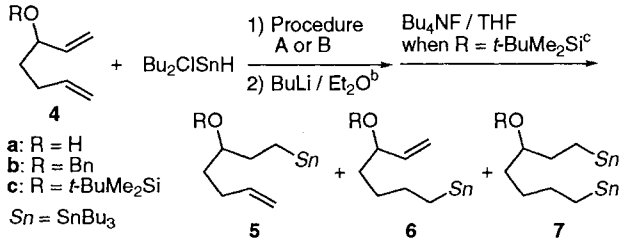
1,6-Heptadien-3-ol (**4a**), including two terminal C-C double bonds, is a good substrate for the evaluation of the directing effect of the hydroxy group. Hydrostannylation of **4a** with Bu_2ClSnH formed 1-stannylated product **5a** selectively (runs 1 and 2 in Table 2).[11] 7-Stannylated product **6a** was not obtained at all. As a result, it turned out that the C1-C2 double bond close to the hydroxy group is more reactive than the C6-C7 double bond. Interestingly, the reaction with Bu_3SnH afforded **7a** as a major product along with **5a** although the total yield was rather low, and, again, **6a** was not formed (Eq. 2). Protection of the hydroxy group with a benzyl group reduced the reactivity of the C1-C2 double bond toward Bu_2ClSnH (runs 3 and 4). The introduction of *t*-$BuMe_2Si$ as a protecting group completely changed the reaction site. Thus, the reaction of **4c** with Bu_2ClSnH followed by the treatment with BuLi and TBAF gave **6a** as a major product without the formation of **5a** (run 5).[12]



11% 17%

Hydrostannylation of 1,5-hexadien-3-ol (**8**) with Bu_2ClSnH and Bu_3SnH was also carried out (Eq. 3). In both cases, three

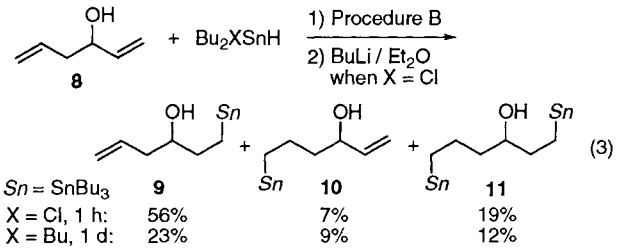
Table 2. Hydrostannylation of 1,6-Dienes **4**[a]



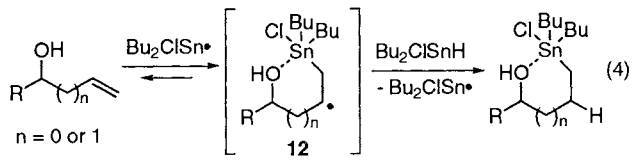
Run	Substrate	Procedure[a]	Time	Product (Yield/%)
1	**4a**	A	1 d	**5a** (61) + **7a** (12)
2	**4a**	B	5 h	**5a** (69) + **7a** (6)
3	**4b**	A	2 d	**5b** (28) + **7b** (10)
4	**4b**	B	5 h	**5b** (30) + **7b** (trace)
5	**4c**	A	2 d	**6a** (26) + **7a** (trace)

[a,b]See Table 1. [c]When R = *t*-BuMe$_2$Si, the crude product was treated with Bu_4NF (2.0 mmol) in THF (5 mL) at rt for 3 h.

possible hydrostannylated products were obtained and 1-stannylated product **9** was a major product. The use of Bu_3SnH decreased the total yield as well as the regioselectivity toward C1-C2 bond, that is, the ratio of **9**+**11** to **10**+**11**. The selective formation of **9** discloses that an allylic hydroxy group has strong directing effect compared with a homoallylic one. Since **6a** was not formed in the hydrostannylation of **4a** with Bu_2ClSnH, the formation of **10** supports our assumption that homoallyl alcohols are more reactive than bishomoallyl alcohols.



The reaction mechanism for homolytic hydrostannylation of alkenes and alkynes includes reversible addition of a stannyl radical followed by H-abstraction from hydrostannane (Eq. 4).[3] In general, homolytic hydrostannylation of alkenes is slower than that of alkynes because of the fast reverse reaction of intermediate β-stannyl alkyl radicals arising from alkenes.[3b,13] The above results of inter- and intramolecular competitive reactions suggest that the coordination of a hydroxy group to the Lewis acidic tin center assists the hydrostannylation of the C-C double bond close to the hydroxy group. Therefore, it is probable that the formation of a chelate ring in intermediate β-stannyl alkyl radical **12** decelerates the reverse reaction by interrupting coplanar interaction between the SOMO and the C-Sn bond and, in consequence, induces the hydrostannylation of allylic and homoallylic alcohols. However, we can not rule out another possibility that the coordination of Bu_2ClSnH or $Bu_2ClSn^{\bullet}$ to the hydroxy group facilitates the radical addition to effect the regioselective hydrostannylation.



In conclusion, we have found that Bu_2ClSnH, a more Lewis acidic hydrostannane than Bu_3SnH, smoothly reacts with allyl and homoallyl alcohols to give γ- or δ-stannylated alcohols in good yields. This work provides a novel example demonstrating that the use of a Lewis acidic radical precursor is effective in accelerating the radical reaction and controlling the reaction site.

References and Notes

1 Review: P. Renaud and M. Gerster, *Angew. Chem., Int. Ed. Engl.*, **37**, 2562 (1998).

2 M. Pereyre, J.-P. Quintard, and A. Rahm, "Tin in Organic Synthesis," Butterworths, London (1987).

3 a) W. P. Neumann and R. Sommer, *Ann.*, **675**, 10 (1964). b) H. G. Kuivila and R. Sommer, *J. Am. Chem. Soc.*, **89**, 5616 (1967).

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5 Mitchell and Moschref have reported that hydrostannylation of propargyl ethers with Bu_2ClSnH gives (*Z*)-vinylstannanes, and the ether oxygen determines the reaction course. T. N. Mitchell and S.-N. Moschref, *Chem. Commum.*, **1998**, 1201.

6 Regio- and stereoselective homolytic hydrostannylations of propargyl alcohols and amines with Bu_3SnH have been reported; however, the origin of the selectivity is not mentioned, or it is independent of the Lewis acid-base interaction. H. E. Ensley, R. R. Buescher, and K. Lee, *J. Org. Chem.*, **47**, 404 (1982); J. C. Anderson and C. A. Roberts, *Tetrahedron Lett.*, **39**, 159 (1998).

7 Homolytic hydrostannylation of 2-propen-1-ol with Bu_2ClSnH has been reported although the directing effect of the hydroxy group is not mentioned in the literature: W. P. Neumann and J. Pedain, *Tetrahedron Lett.*, **1964**, 2461. We found that internal alkenes bearing a hydroxy group at the allylic position underwent no hydrostannylation by procedure A or B.

8 K. Nozaki, K. Oshima, and K. Utimoto, *J. Am. Chem. Soc.*, **109**, 2547 (1987).

9 The addition of Et_3B or AIBN considerably accelerates the hydrostannylation with Bu_2ClSnH (see Ref 7); however, it also proceeds without radical initiator. For example, the reaction of **1a** with Bu_2ClSnH in hexane at rt for 2 days gave **2a** in 74% yield, which was determined by ^1H NMR analysis of the crude product. Under the same conditions, 10 mol% of galvinoxyl prevented the reaction completely. This observation suggests that the spontaneous hydrostannylation proceeds *via* a radical chain mechanism.

10 A. K. Sawyer and H. G. Kuivila, *Chem. Ind.*, **1961**, 260.

11 No cyclized product was obtained in the hydrostannylation of **4** although radical cyclization of dienes using hydrostannanes has been reported in the following papers: S. Hanessian and R. Léger, *J. Am. Chem. Soc.*, **114**, 3115 (1992); R. H. Fish, H. G. Kuivila, and I. J. Tyminski, *J. Am. Chem. Soc.*, **89**, 5861 (1967). This result indicates that the intramolecular addition of an intermediate β-stannylalkyl radical generated by the addition of $Bu_2ClSn^{\bullet}$ to **4** is much slower than the intermolecular H-abstraction of the intermediate from Bu_2ClSnH. The rate difference would arise from the structure of **4** bearing no substituent accelerating the cyclization in addition to high H-donating ability of Bu_2ClSnH and its high concentration.

12 This is probably because the bulkiness of the *t*-BuMe$_2$Si group hinders the addition of $Bu_2ClSn^{\bullet}$ to the C1-C2 double bond and/or the following H-abstraction from Bu_2ClSnH in the absence of the coordination of the ether oxygen to the Lewis acidic tin center. See Eq. 4.

13 G. Stork and R. Mook, Jr., *J. Am. Chem. Soc.*, **109**, 2829 (1987).