Buta-2,3-dienylstannanes, effective reagents for regioselective buta-1,3-dienylation of aldehydes and acetals

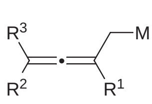
Meiming Luo, Yoshiharu Iwabuchi and Susumi Hatakeyama*

Faculty of Pharmaceutical Sciences, Nagasaki University, Nagasaki 852-8521, Japan.
E-mail: susumi@net.nagasaki-u.ac.jp

Received (in Cambridge, UK) 20th November 1998, Accepted 11th December 1998

Two buta-2,3-dienylstannanes, 1-tri-*n*-butylstannylbuta-2,3-diene and 1-triphenylstannylbuta-2,3-diene, have been prepared and shown to react with aldehydes and acetals under Lewis acid catalyzed conditions producing (buta-1,3-dien-2-yl)methanol derivatives in high yields.

Recently, buta-2,3-dienylsilanes **1** (M = SiR_3)[1,2] and buta-2,3-dienylboronates **1** [M = $B(OR)_2$],[3] have appeared as useful reagents for the synthesis of (buta-1,3-dien-2-yl)methanol derivatives **2** from aldehydes and acetals. In addition, we have demonstrated that these dienols **2** are valuable precursors for the syntheses of a variety of natural products.[1,4] As part of our interest in developing a catalytic asymmetric reaction of a buta-2,3-dienylmetal **1** with an aldehyde using a chiral Lewis acid,† we directed our attention to buta-2,3-dienylstannanes **1** (M = SnR_3) which are unprecedented as synthetic reagents. Here, we report the first practical syntheses of 1-tri-*n*-butylstannylbuta-2,3-diene **3** and 1-triphenylstannylbuta-2,3-diene **4** and their Lewis acid catalyzed reactions with aldehydes and acetals.



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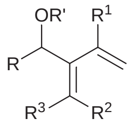

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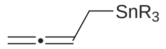
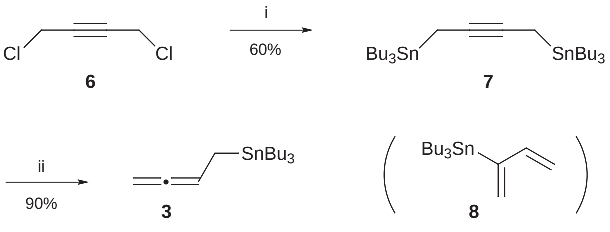


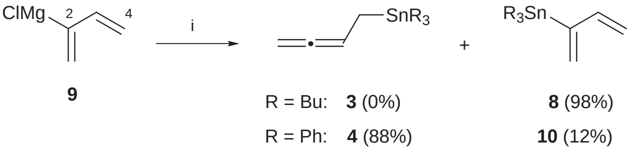
3 R = Bu
4 R = Ph
5 R = Me

Reich and co-workers reported[5] that treatment of 1,4-bis-(trimethylstannyl)but-2-yne with HCl in $CDCl_3$ caused protomonodestannylation to give 1-trimethylstannylbuta-2,3-diene **5**. However, to the best of our knowledge, the results of this NMR experiment have not been further examined in detail. This situation allowed us to examine in detail protomonodestannylations of 1,4-bis(trialkylstannyl)but-2-ynes as one possible route to buta-2,3-dienylstannanes (Scheme 1). After many discouraging results, we eventually found good reaction conditions wherein large quantities of 1-tri-*n*-butylstannylbuta-2,3-diene **3** are obtained with > 95% purity from 1,4-bis(tri-*n*-butylstannyl)but-2-yne **7**. Thus, treatment of **7**, prepared by the reaction of 1,4-dichlorobut-2-yne **6** with tri-*n*-butylstannyllithium,‡ with concentrated HCl in a 16:1 mixture of Et_2O and THF at 0 °C gave **3** cleanly in 90% yield.§ This HCl-promoted protomonodestannylation also turned out to proceed in a reasonable yield (77%) in Et_2O although the reaction was rather sluggish even at room temperature. When THF was used as solvent for this reaction, the yield of **3** decreased to 42%, possibly because of its further protodestannylation giving buta-1,3-diene. It is important to note that purification of **3** by silica gel column chromatography caused isomerization to 2-tri-*n*-butylstannylbuta-1,3-diene **8**. The ratio of **3** and **8** was at best 1 : 1 under these unsatisfactory conditions and varied depending upon the amount of silica gel used. This isomerization, however, could be completely suppressed by use of silica gel pretreated with Et_3N. Compound **3** thus purified was thermally stable and no isomerization occurred during distillation.



Scheme 1 *Reagents and conditions*: i, Bu_3SnLi, THF, −78 °C; ii, conc. HCl, Et_2O–THF, 0 °C.

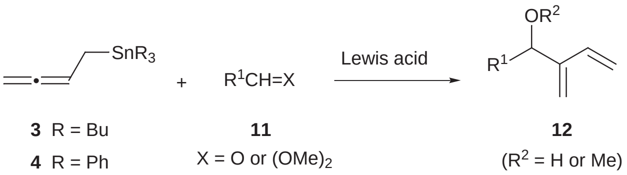
We also investigated the reaction of Ph_3SnCl or Bu_3SnCl with the Grignard reagent **9**[6] prepared from chloroprene (2-chlorobuta-1,3-diene) (Scheme 2). We found that, in the case of Ph_3SnCl, the reaction occurred preferentially at the C4 position to give a 88 : 12 mixture of 1-triphenylstannylbuta-2,3-diene **4** and 2-triphenylstannylbuta-1,3-diene **10** in quantitative yield. Recrystallization of this mixture from *n*-hexane afforded pure **4** in 73% yield.¶ Interestingly, as previously reported,[7] Bu_3SnCl reacted with the Grignard reagent **9** with complete C2 selectivity to give 2-tri-*n*-butylstannylbuta-1,3-diene **8** quantitatively.



Scheme 2 *Reagents and conditions*: i, Bu_3SnCl or Ph_3SnCl, THF, −78 °C.

Having developed practical methods for the preparation of buta-2,3-dienylstannanes **3** and **4**, we then investigated their Lewis acid catalyzed reactions with various aldehydes and acetals (Scheme 3). Table 1 summarizes Lewis acid catalyzed additions of **3** and **4** to aldehydes. It is evident that this reaction has broad applicability for the preparation of **12** (R^2 = H) and $BF_3 \cdot Et_2O$ is the catalyst of choice, except for the two examples listed in entries 8 and 10. It is also apparent that **3** is much more reactive than **4** in this reaction. Compound **3** was found to gradually isomerize to **8** under these conditions, whereas compound **4** did not undergo such Lewis acid catalyzed isomerization.

As can be seen from Table 2, both **3** and **4** again reacted with acetals in good yields. The mixed titanium reagent [$3TiCl_4 \cdot Ti(OPr^i)_4$] was found to give better results than $BF_3 \cdot Et_2O$, especially in the cases of aliphatic acetals (entries 1, 2, 10 and 11). Conversely, the reaction of cinnamaldehyde dimethyl acetal with **3** took place almost quantitatively under $BF_3 \cdot Et_2O$



Scheme 3

Table 1 Lewis acid catalyzed addition of **3** and **4** to aldehyde **11** (X = O) giving **12** (R^2 = H)[a]

Entry	**3** or **4**	R^1	Lewis acid	Solvent	*t*/h	Yield (%)[b]
1	**3**	$Ph(CH_2)_2$	$BF_3\cdot Et_2O$	CH_2Cl_2	2	57
2	**3**	$Ph(CH_2)_2$	$BF_3\cdot Et_2O$	toluene	9	92
3	**3**	$Ph(CH_2)_2$	$TiCl_4$	CH_2Cl_2	10	17[c]
4	**3**	$Ph(CH_2)_2$	$3TiCl_4\cdot Ti(OPr^i)_4$	toluene	8	44[c]
5	**3**	$Ph(CH_2)_2$	MgI_2	CH_2Cl_2	4	51[d]
6	**3**	$PhCH_2$	$BF_3\cdot Et_2O$	toluene	12	83
7	**3**	$PhCH_2$	$TiCl_4$	CH_2Cl_2	0.3	64
8	**3**	(*E*)-PhCH=CH	$BF_3\cdot Et_2O$	toluene	10	0[e]
9	**3**	Ph	$BF_3\cdot Et_2O$	toluene	9	96
10	**4**	Ph	$BF_3\cdot Et_2O$	CH_2Cl_2	10	0[e]
11	**4**	Ph	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	10	40 (65)[f]
12	**3**	n-C_7H_{15}	$BF_3\cdot Et_2O$	toluene	12	87
13	**4**	n-C_7H_{15}	$BF_3\cdot Et_2O$	CH_2Cl_2	23	85
14	**3**	c-C_6H_{11}	$BF_3\cdot Et_2O$	toluene	12	90
15	**4**	c-C_6H_{11}	$BF_3\cdot Et_2O$	CH_2Cl_2	16	86

[a] All reactions were carried out at −78 °C in the indicated solvent (0.13 mol dm^{-3}) using buta-2,3-dienylstannane (2 equiv.), aldehyde (1 equiv.), and Lewis acid (1 equiv.) unless stated otherwise. [b] Isolated yield. [c] The aldehyde was partly cyclyzed to indan-1-ol which underwent further reaction to produce several by-products. [d] The reaction was carried out at room temperature. [e] Most of the aldehyde was recovered. [f] Yield in parenthesis based on the consumed aldehyde.

Table 2 Lewis acid catalyzed addition of **3** and **4** to acetal **11** (X = $(OMe)_2$) giving **12** (R^2 = Me)[a]

Entry	**3** or **4**	R^1	Lewis acid	Solvent	*t*/h	Yield (%)[b]
1	**3**	$Ph(CH_2)_2$	$BF_3\cdot Et_2O$	toluene	12	0[c]
2	**3**	$Ph(CH_2)_2$	$3TiCl_4\cdot Ti(OPr^i)_4$	toluene	5	95
3	**3**	$PhCH_2$	$3TiCl_4\cdot Ti(OPr^i)_4$	toluene	5	81
4	**3**	(*E*)-PhCH=CH	$BF_3\cdot Et_2O$	toluene	10	99
5	**3**	(*E*)-PhCH=CH	$3TiCl_4\cdot Ti(OPr^i)_4$	toluene	10	48
6	**3**	Ph	$BF_3\cdot Et_2O$	toluene	10	89
7	**3**	Ph	$3TiCl_4\cdot Ti(OPr^i)_4$	toluene	4	89
8	**4**	Ph	$BF_3\cdot Et_2O$	toluene	10	86
9	**4**	Ph	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	6	70
10	**3**	n-C_7H_{15}	$BF_3\cdot Et_2O$	toluene	9	0[c]
11	**3**	n-C_7H_{15}	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	4	86
12	**4**	n-C_7H_{15}	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	7	91
13	**3**	c-C_6H_{11}	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	4	96
14	**4**	c-C_6H_{11}	$3TiCl_4\cdot Ti(OPr^i)_4$	CH_2Cl_2	8	89

[a] Reactions were carried out at −78 °C in the indicated solvent (0.13 mol dm^{-3}) using buta-2,3-dienylstannane (**3**: 2 equiv. **4**: 1.2 equiv.), acetal (1 equiv.) and Lewis acid (1 equiv.). [b] Isolated yield. [c] Most of the aldehyde was recovered.

catalyzed conditions and $3TiCl_4\cdot Ti(OPr^i)_4$ produced poor result in this particular case (entries 4 and 5).

In conclusion, we have successfully synthesized two buta-2,3-dientylstannanes, 1-tri-*n*-butylstannylbuta-2,3-diene **3** and 1-triphenylstannylbuta-2,3-diene **4**, in >95% isomeric purity for the first time. These buta-2,3-dienylstannanes react with various aldehydes and acetals regioselectively in a 1,3-rearrangement fashion to give (buta-1,3-dien-2-yl)methanol derivatives in excellent yields. In comparison with the related silicon[1] and boron reagents,[3] buta-2,3-dienylstannanes have the advantage of broad applicability in buta-1,3-dienylations of both aldehydes and acetals. The development of a catalytic asymmetric reaction of buta-2,3-dienylstannanes with aldehydes is the focus of current investigations.

This work was supported by the Japan Society for the Promotion of Science (postdoctoral fellowship for M. L.). We gratefully acknowledge the Tosoh Corporation (Nanyo Research Laboratory, Japan) for providing chloroprene.

Notes and references

† A catalytic asymmetric version of this process using either buta-2,3-dienylsilanes or buta-2,3-dienylboronates has not been successfully achieved yet.

‡ Prepared according to Reich's method for 1,4-bis(trimethylstannyl)but-2-yne (ref. 5).

§ Experimental procedure for **3**: To a stirred solution of **7** (7.93 g, 12.5 mmol) in Et_2O (80 ml) with cooling in an ice bath was added a mixture of concentrated HCl (1.3 ml) and THF (5 ml). After stirring at 0 °C for 8 h, the reaction mixture was basified with 5% NaOH (10 ml) and extracted with Et_2O. The extract was washed with water, dried over $MgSO_4$, and concentrated *in vacuo*. Purification by column chromatography [SiO_2 (30 g) pretreated with Et_3N (30 g); *n*-hexane] afforded **3** (3.86 g, 90%), bp 150 °C (0.2 mmHg) (Kugelröhr).

¶ Experimental procedure for **4**: A flame-dried flask was charged with THF (30 ml) and Grignard reagent **9** (1.6 mol dm^{-3} in THF, 12.5 ml, 20 mmol) under argon and then a solution of Ph_3SnCl (7.71 g, 20 mmol) in THF (15 ml) was added dropwise at −78 °C. After being stirred at −78 °C for 30 min, the reaction mixture was quenched with 5% NaOH (10 ml) and extracted with Et_2O. The extract was dried over $MgSO_4$, concentrated *in vacuo*, and chromatographed [SiO_2 (30 g) pretreated with Et_3N (30 g); *n*-hexane] to give an 88 : 12 mixture of **4** and **10** as a colorless viscous oil (8.05 g) which solidified during overnight storage in a refrigerator. Recrystallization of this crystalline solid from *n*-hexane afforded **4** (5.86 g, 73%) as colorless crystals (mp 54–55 °C).

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Communication 8/09081E