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Allylstannylation of Alkynes *via* a Radical Process: Stereoselective Synthesis of Di- and Tri-substituted Vinylstannanes

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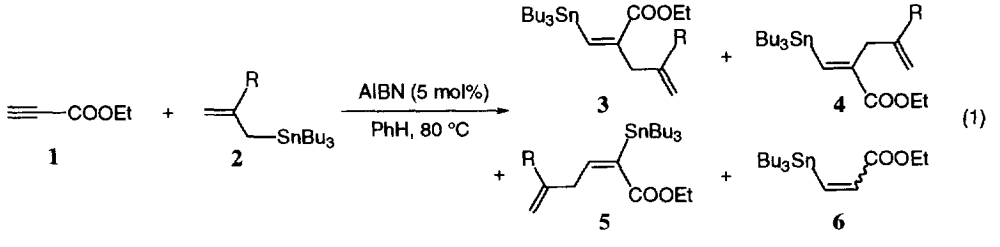
Abstract: In the presence of AIBN, allylstannanes bearing an electron-withdrawing group at the β-position easily reacted with terminal and electron-deficient internal alkynes to give β-allyl-substituted vinylstannanes in moderate to good yields. The allylstannylation proceeds with *anti* addition exclusively. Copyright © 1996 Elsevier Science Ltd

Carbometallation of alkenes and alkynes is one of the most useful reactions for the stereo-controlled construction of organic molecules, because the carbometallation reaction usually proceeds with high regio- and stereoselectivity, and the resultant organometallics react with various electrophiles with retention of the stereochemical integrity.[1] Previously, we have reported that allylstannanes bearing an electron-withdrawing group at the β-position easily react with electron-deficient alkenes to introduce both allyl and stannyl groups to the carbon-carbon double bond.[2] This allylstannylation reaction is a novel type of carbometallation reaction *via* a radical process. We report herein that several alkynes undergo the allylstannylation to give vinylstannanes with high regio- and stereoselectivity.[3]

We first carried out the reaction of ethyl propiolate (**1**) with the allylstannanes **2a-f** (eq. 1 and Table 1). Treatment of **1** with 4 equivalents of the allylstannane **2a** (R = H) in the presence of AIBN gave a mixture of the α-allyl-β-stannyl-substituted acrylate **3a** (*anti* adduct, 12% yield) and the (*Z*)-β-stannylacrylate **6** (1.4% yield) after purification by silica-gel column chromatography. The formation of **4a** and **5a**, stereo- and regioisomers of **3a**, was also observed although their yields were fairly low (<0.5% yield).[4,5] On the other hand, β-substituted allylstannanes exhibited higher reactivity than **2a**. In particular, the introduction of an electron-withdrawing group at the β-position significantly enhances the reactivity. Thus, the allylstannanes **2e** (R = COOMe) and **2f** (R = CN) smoothly added to **1** to give the *anti* adducts **3e** and **3f** as major products in 70% and 74% isolated yields, respectively.



(1)

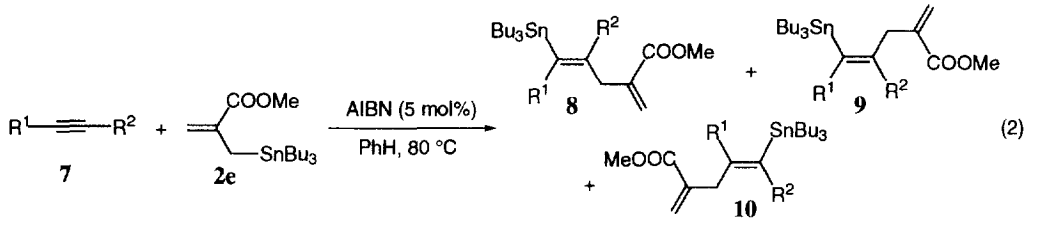
Table 1. Allylstannylation of ethyl propiolate with various allylstannanes[a]

Entry	Allylstannane R		Time / h	Yield / % 3[b,c]	4 + 5[d]	4 : 5[e]
1	H	(**2a**)	4	12[f,g]	< 1[h]	2 : 1
2	Me	(**2b**)	2	27[f]	< 2[h]	3 : 1
3	$SiMe_3$	(**2c**)	2	38[g]	< 2	1 : 1
4	Ph	(**2d**)	1	61	< 5	1 : 2
5	COOMe	(**2e**)	1	70[g]	< 15	11 : 4
6	CN	(**2f**)	1	74[g]	< 12	11 : 1

[a]Reaction conditions: alkyne:allylstannane:AIBN=1:4:0.05 (molar ratio), benzene (5 ml per 1 mmol of alkyne), 80 °C. [b]Isolated yield of a pure product except for entries 1-2. [c]The configurations of **3** and **4** were assigned by NOE experiments and/or chemical shifts of the olefinic protons. See ref. 4. [d]A mixture of the vinylstannanes **4**, **5** and unidentified impurities was obtained after purification of silica-gel column chromatography. See ref. 5. The assignment of the geometry of **5** was based on the coupling constant between the olefinic proton and ^{119}Sn or ^{117}Sn. See ref. 6. [e]Determined by ^1H NMR analysis. [f]Including (*Z*)-**6**. The yield was estimated by ^1H NMR analysis. [g]The allylstannane was recovered in 62-74% based on the initial amount. [h]Including (*E*)-**6**.

In order to investigate the limitation of the allylstannylation, a variety of alkynes were subjected to the reaction with **2e** (eq. 2 and Table 2). Phenylacetylene (**7a**) efficiently reacted with **2e** to give the vinylstannane **8a** in 94% yield without other isomers. The reaction of 1-dodecyne (**7b**) also gave only **8b** among the expected destannylated products, but isolation of **8b** from the reaction mixture including **2e** and its dimer was a laborious process.[2] Although the yield of **8b** was estimated to be 63% by the ^1H NMR analysis of the crude product, it was isolated in only 44% yield (>98% pure) by distillation. Destannylation of the crude product with HCl-CH_3CN provided the 1,4-diene **11** in 70% isolated yield. The reactivity of **7b** is in sharp contrast to that of 1-decene, which was insensitive to **2e** under the same reaction conditions.[2,7] The present reaction tolerates the presence of a hydroxyl group as shown in some other radical reactions.[8,9] 3-Butyn-1-ol (**7c**) as well as **7a** and **7b** was converted to a single isomer of the allylstannylated products, while the use of 3-butyn-2-ol (**7d**) resulted in the formation of two regioisomers (**8d** and **10d**) and the δ-lactone **12**.[9] Protection of the hydroxyl group of **7d** improved the regioselectivity and suppressed the lactonization (entry 5).

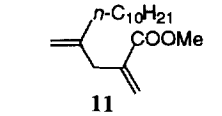
Internal alkynes conjugated with an ester group also underwent the allylstannylation. The reaction of methyl 2-heptynoate (**7f**) gave the *anti* adducts **8f** and **10f** with a 1:2 regioselectivity along with the allylvinylstannane **13**.[10,11] Similar regioselective addition of a stannyl group to the carbon α to the ester group was also observed in the hydrostannylation of **7f** with Bu_3SnH and AIBN.[12] When methyl 3-phenyl-2-propynoate (**7g**) was employed, the selectivity increased to more than 40:1. Dimethyl acetylenedicarboxylate (**7h**), a highly electron-deficient alkyne, also underwent the allylstannylation in high efficiency in an *anti* addition mode.[13] In contrast, phenyl- and alkyl-substituted internal alkynes were much less reactive to **2e** than the electron-deficient alkynes (entries 9 and 10).



(2)

Table 2. Allylstannylation of various alkynes with allylstannane **2e**[a]

Entry	Alkyne R^1	Alkyne R^2		Time / h	Products (yield / %)[b,c]
1	H	Ph	(**7a**)	1	**8a** (94)
2	H	n-$C_{10}H_{21}$	(**7b**)	6	**8b** (44), **11** (70)[d]
3	H	CH_2CH_2OH	(**7c**)	2	**8c** (69)
4	H	$CH(OH)CH_3$	(**7d**)	2	**8d+10d** (39, 86:14)[e] + **12** (<4)[f]
5	H	$CH(OAc)CH_3$	(**7e**)	2	**8e** (62)
6	Bu	COOMe	(**7f**)	2	**8f** (15) + **10f** (38) + **13** (7, 87:13)[g]
7	Ph	COOMe	(**7g**)	1	**8g** (2) + **10g** (84)
8	MeOOC	COOMe	(**7h**)	1	**8h** (85) + **9h** (trace)
9	Bu	Ph	(**7i**)	6	**8i** (19)
10	n-C_5H_{11}	n-C_5H_{11}	(**7j**)	24	No reaction.



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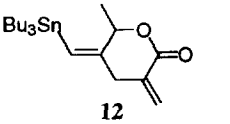

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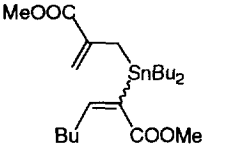
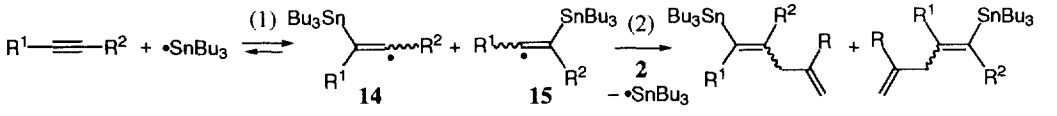


13

[a]See footnote a in Table 1. [b]The configuration of product was assigned by NOE experiments and/or the coupling constant between ^1H and ^{119}Sn or ^{117}Sn. See ref. 10 and 13 regarding the assignment of the configurations of **8f**, **10f-g**, **8h**, and **9h**. [c]Isolated yield. [d]See the text. [e]Isomeric ratio, **8d:10d**. [f]Including unidentified impurities. [g]Isomeric ratio, (*E*)-**13**:(*Z*)-**13**.

A plausible mechanism for the allylstannylation of alkynes is illustrated in Scheme 1. First, a stannyl radical generated from an allylstannane **2** by the action of AIBN adds to an alkyne reversibly (step (1)). Then, the resulting vinyl radicals **14** and **15** react with **2** to afford allylstannylated products and regenerate the stannyl radical (step (2)). As described above, the use of an electron-withdrawing group as R is essential for successful allylstannylation. This is probably due to the acceleration of the step (2) by the electron-withdrawing group, since carbon radicals including alkyl and vinyl radicals are generally nucleophilic.[1,8a]

Scheme 1. Mechanism for the Allylstannylation



In the case of terminal alkynes (R^1 = H), the stannyl radical selectively attacks the terminal acetylenic carbon to avoid the steric repulsion from the substituent R^2. The formation of the regioisomers **5** and **10d** in the reactions of **1** and **7d** indicates that the oxygen functionalities such as the ester and hydroxyl groups facilitate the addition of the stannyl radical to the internal acetylenic carbon adjacent to them.[9] The directing effect was distinctly observed in the allylstannylation of the internal alkynes **7f** and **7g**. However, the origin of the directing effect remains obscure at present. The stereochemistry of the products is mainly determined in the step (2).[14] The attack of **2** to the radical center of **14** or **15** takes place at the opposite side to the stannyl group due to its steric hindrance, and therefore, the allylstannylation proceeds in an *anti* fashion predominantly.[8a,15]

In conclusion, we have developed a new method for the stereoselective synthesis of di- and tri-substituted vinylstannanes. Since the stannyl group of vinylstannanes can be converted to various substituents with stereochemical retention, the present method serves for the stereoselective construction of multi-substituted and highly functionalized alkenes.[16]

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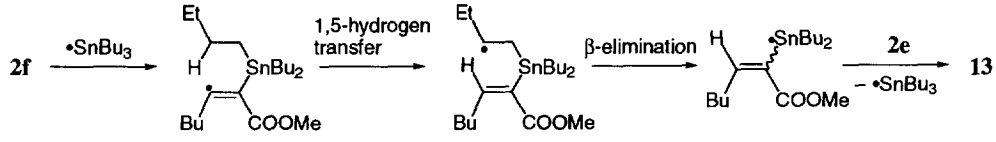
References and Note

1. Knochel, P. *Comprehensive Organic Synthesis*; Trost, B. M., Ed.; Pergamon Press: Oxford, 1991; Vol. 4, pp. 865-911.
2. Miura, K.; Matsuda, T.; Hondo, T.; Ito, H.; Hosomi, A. *Synlett*, **1996**, 555-556.
3. Recently, Yamamoto *et al.* have reported the $ZrCl_4$-catalyzed *trans*-allylstannylation of certain alkynes. Asao, N.; Matsukawa, Y.; Yamamoto, Y. *Chem. Commun.* **1996**, 1513-1514.
4. *Syn* adducts **4** could be obtained by the isomerization of **3** with Bu_3SnH-Et_3B although the yields were less than 5%. Taniguchi, M.; Nozaki, K.; Miura, K.; Oshima, K.; Utimoto, K. *Bull. Chem. Soc. Jpn.* **1992**, *65*, 349-353.
5. The authentic sample of **5a** was synthesized by the hydrostannylation of ethyl 5-hexen-2-ynoate with Bu_3SnH-AIBN. Leusink, A. J.; Budding, H. A. *J. Organomet. Chem.* **1968**, *11*, 533-539. The presence of regioisomers **5b-f** was strongly supported by the characteristic peak of the olefinic proton β to the stannyl group in addition to the peaks of the other olefinic and allylic protons in the ^1H NMR spectra of the mixtures.
6. Leusink, A. J.; Budding, H. A.; Marsman, J. W. *J. Organomet. Chem.* **1967**, *9*, 285-294.
7. It is probably because the intermediary β-stannylalkyl radical arising from 1-decene releases the stannyl radical faster than the β-stannylvinyl radical **14** (R^1 = H, $R^2 = C_{10}H_{21}$), and the fast β-elimination prevents the following allylation with **2e**. Stork, G.; Mook, R. Jr. *J. Am. Chem. Soc.* **1987**, *109*, 2829-2831.
8. (a) Miura, K.; Itoh, D.; Hondo, T.; Hosomi, A. *Tetrahedron Lett.* **1994**, *35*, 9605-9608. (b) Keck, G. E.; Yates, J. B. *J. Am. Chem. Soc.* **1982**, *104*, 5829-5831. (c) Kozikowski, A. P.; Nieduzak, T. R.; Scripko, J. *Organometallics*, **1982**, *1*, 675-676.
9. For the hydrostannylation of propargyl alcohols *via* a radical process, see (a) Konoike, T.; Araki, Y. *Tetrahedron Lett.* **1992**, *33*, 5093-5096, (b) Ensley, H. E.; Buescher, R. R.; Lee, K. *J. Org. Chem.* **1982**, *47*, 404-408.
10. It is well-known that the protonolysis of vinylstannanes proceeds with retention of the configuration. Therefore, we carried out the protonolysis of **8f** and **10f-g** with AcOH-MeOH or HCl-CH_3CN to determine their geometries. The destannylated products were characterized by ^1H NMR analysis involving NOE experiments. Alvanipour, A.; Eaborn, C.; Walton, D. R. M. *J. Organomet. Chem.* **1980**, *201*, 233-247.
11. The formation of allylvinylstannane **13** can be explained by the stepwise mechanisms shown below, which consist of (1) addition of Bu_3Sn• to the α-carbon of **7f**, (2) the 1,5-hydrogen transfer from sp^3-carbon to sp^2-carbon, (3) the β-elimination of the stannyl radical from the rearranged radical, and (4) the allylation of the stannyl radical by S_H' process. For the 1,5-hydrogen transfer, see Bogen, S.; Malacria, M. *J. Am. Chem. Soc.* **1996**, *118*, 3992-3993.



12. The reaction of **7f** with Bu_3SnH in the presence of AIBN gave α- and β-stannylacrylates in 58% (E:Z = 1:2) and 29% (E only), respectively. The hydrostannylation of ethyl 2-butynoate has been reported by Leusink *et al.* See ref. 5.
13. The configurations of **8h** and **9h** are tentatively assigned by TLC analysis (Merck 1.05715., silica gel 60 F_{254}). Dimethyl fumarate has a higher R_f value than dimethyl maleate(hexane-AcOEt (3:1), R_f (fumarate) = 0.59, R_f (maleate) = 0.42). In addition, (*Z*)-β-stannylacrylates **3** are eluted earlier than their (*E*)-isomers **4**. These facts support the finding that **8h**, whose R_f value is higher than that of **9h**, has Z-geometry (hexane-AcOEt (5:1), R_f (**8h**) = 0.48, R_f (**9h**) = 0.34). The assignment is consistent with the configuration deduced from the reaction mechanism. We attempted the protodestannylation of **8h** with HCl-CH_3CN to determine the geometry, but the reaction gave a 5:4 mixture of E- and Z-isomers of the destannylated products. It turned out that **8h** underwent protodestannylation without stereochemical retention, unlike **8f** and **10f-g**.
14. There is a possibility that the *syn* adduct is formed by stannyl radical-mediated isomerization of the *anti* adduct. See ref. 4 and the following report. Leusink, A. J.; Budding, H. A.; Drenth, W. *J. Organomet. Chem.* **1968**, *11*, 541-547.
15. (a) Giese, B.; González-Gómez, J. A.; Lachhein, S.; Metzger, J. O. *Angew. Chem. Int. Ed. Engl.* **1987**, *26*, 479-480. (b) Journet, M.; Malacria, M. *J. Org. Chem.* **1992**, *57*, 3085-3093.
16. (a) Pereyre, M.; Quintard, J.-P.; Rahm, A. *Tin in Organic Synthesis*; Butterworth: London, 1987. Recent papers: (b) Allred, G. D.; Liebeskind, L. S. *J. Am. Chem. Soc.*, **1996**, *118*, 2748-2749, (c) Piers, E.; Romero, M. A. *J. Am. Chem. Soc.* **1996**, *118*, 1215-1216, (d) Piers, E.; McEachern, E. J.; Romero, M. A. *Tetrahedron Lett.*, **1996**, *37*, 1173-1176, (e) Takeda, T.; Matsunaga, K.; Kabasawa, Y.; Fujiwara, T. *Chem. Lett.* **1995**, 771-772.

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