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Chemoselective Silylzincation of Functionalized Terminal Alkynes Using Dianion-Type Zincate (SiBNOL-Zn-ate): Regiocontrolled Synthesis of Vinylsilanes

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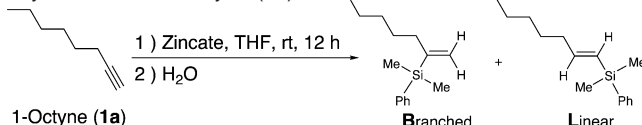
Carbon–carbon double bonds are key structural features of organic molecules, and control of C=C bond geometry has been one of the central issues in organic synthesis.¹ The intermolecular silylmatalation of alkynes constitutes an excellent method for construction of multisubstituted olefins.^{2–5} However, controlling the chemo- and regioselectivity in the silylmatalation of unsymmetrical alkynes remains an important challenge. In particular, very limited success has been reported in regioselective silylmatalation to give branched vinylsilanes from terminal alkynes.^{2b–e} In 1985, Oshima and co-workers reported that highly branch-selective silylzincation of 1-dodecyne could be realized by using lithium di-*tert*-butyl(dimethylphenylsilyl)zincate.^{2d} However, only a limited number of examples of the reaction have been examined, and the substrate generality and chemoselectivity of this reaction, therefore, are still unclear. In addition, the reaction requires 2 equiv of the zincate and addition of a catalytic amount of CuCN. We disclose here a newly designed dianion-type⁶ silylzincate complex that promotes highly chemo- and regioselective silylzincation of unfunctionalized and functionalized terminal alkynes *without any transition-metal catalyst*. We also show that the resultant vinylzincate can be a potent intermediate for regiocontrolled trisubstituted olefins, which provide basic architecture for functionalized materials.

Our initial studies using 1-octyne (**1a**) as a model substrate, aimed at identifying favorable reaction conditions, revealed that a dimethylphenylsilyl (DMPS) group as the silyl moiety and THF as a solvent were suitable starting points for optimization of the silylzincation reaction conditions. At this early stage, several attempts to use the monoanion-type silylzincates proved unsuccessful in terms of the reactivity (yields) and (branch-)selectivity. On the other hand, 1 equiv of dianion-type silylzincates turned out to promote the silylzincation of **1a**, without any catalysts, in good to excellent yields at room temperature. Various dianion-type zincates were examined (Table 1), and a combination of biphenoxo and ^tBu (SiBNOL-Zn-ate) (run 6) gave the best result in terms of yield and branch-selectivity.⁷

Representative results of the silylzincation of various terminal alkynes by SiBNOL-Zn-ate are summarized in Table 2. Not only alkyl groups, but also a variety of polar functional groups including an aliphatic chloride, amide, ester, and TMS (entries 4–7, 9, 13, 16) are tolerated in the reaction.⁸ Substrates containing an O–H or an N–H moiety, such as aliphatic alcohols, carboxylic acid, and amine, can also be utilized by employing SiBNOL-Zn-ate, and no self-condensation was observed (entries 7, 8, 14, 15). A π -deficient heteroaromatic moiety also caused no problem (entry 11). Thus, this silylzincation has a high compatibility with functional groups, presumably due to the soft nucleophilicity of zincates.⁸

Some important aspects of the regioselectivity of this silylzincation can be drawn from the data in the Table 2. (1) As evidenced

Table 1. Screening of Zincates for Highly Branch-Selective Silylzincation of 1-Octyne (**1a**)^a



Run	Zincate	Yield ^b (%)	Ratio B : L	Run	Zincate	Yield ^b (%)	Ratio B : L
1		85 ^c	56 : 44	4		85 ^d	81 : 19
2		42 ^c 89 ^d	73 : 27 74 : 26	5		100 ^d	92 : 8
3		100 ^c	53 : 47	6		100 ^d	99 : 1

^a Unless otherwise noted, the silylzincation was carried out using zincate (1.1 equiv) and substrate (1.0 equiv) in THF at room temperature for 12 h. ^b Isolated yield. ^c Counteranions (M⁺, M⁺) were 2Li⁺. ^d Counteranions were Li⁺Mg⁺Cl or 2Mg⁺Cl.

by the examples in the left column of Table 2, the reactions of SiBNOL-Zn-ate with terminal alkyne containing an acyclic alkyl moiety as well as 1-octyne (**1a**) and with terminal alkynes containing cyclic alkyl, benzyl, and polar functional groups distal from the reaction site (triple bond) showed high branch selectivities. To our knowledge, this reaction is the first example of an efficient branch-selective silylmatalation with wide substrate generality. (2) On the other hand, electronic activation of electrophilicity at the terminal carbon of the alkynes, through introduction of a TMS, phenyl, or pyridyl group (entries 9–11), gave completely reversed regioselectivity, i.e., the linear products are favored over the branched products in these reactions. In the case of the ferrocenyl moiety (entry 12), the electronic effect may be counterbalanced by its steric hindrance, since the regioselectivity of this silylzincation disappeared. (3) To clarify the possible chelation effect in this silylzincation, the reactions of terminal alkynes bearing a chelatable heteroatom were examined (entries 13–16). Linear vinylsilane derivatives were preferentially obtained, as would be expected if a chelation effect is involved.

To investigate the chemoselectivity of this silylzincation, the reactivities of SiBNOL-Zn-ate with a terminal alkene, diene, internal alkyne, and terminal-internal mixed diyne were next examined (Scheme 1). The functional group specificity of this silylzincation is very high because of a transition-metal-free reaction, and the olefin **3** or diene **4** did not react at all. In the reaction of an internal alkyne, 3-hexyne (**5**), this silylzincation also did not proceed at room temperature, while it occurred at higher temperature (40 °C

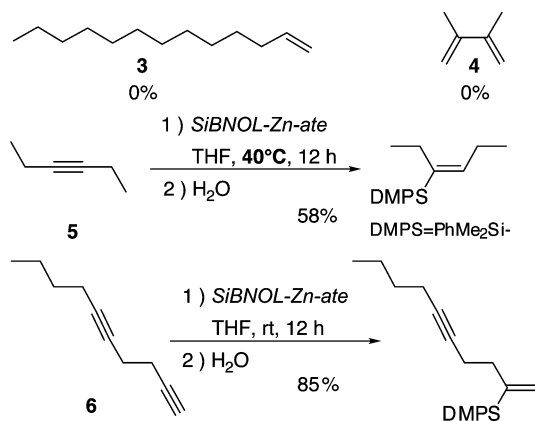
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Table 2. Silylzincation of Various Functionalized Terminal Acetylenes^a

Entry	R	Yield ^b (%)	Ratio B : L	Entry	R	Yield ^b (%)	Ratio B : L
1		88	95 : 5	9		73	0 : 100
2		94	92 : 8	10		100	12 : 88
3		100	75 : 25	11		100	0 : 100
4		89	94 : 6	12		92	50 : 50
5		92	74 : 26	13		83 ^d	12 : 88
6		100	86 : 14	14 ^c		100	15 : 85
7 ^c		99	81 : 19	15		99	8 : 92
8 ^c		80	85 : 15	16		76	0 : 100

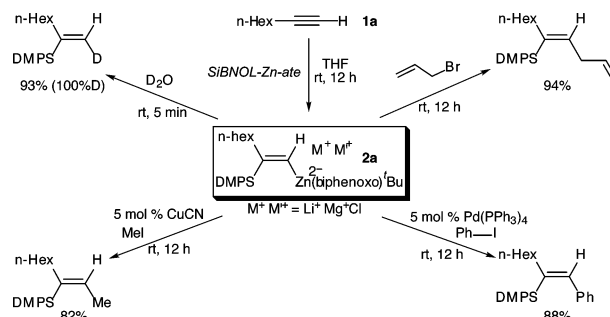
^a Unless otherwise noted, the silylzincation was carried out using SiBNOL-Zn-ate (1.1 equiv) and substrate (1.0 equiv) in THF at room temperature for 12 h. ^b Isolated yield. ^c The reaction was carried out using SiBNOL-Zn-ate (2.2 equiv). ^d The reaction was carried out at -78°C for 4 h to prevent from the formation of allene byproduct.

Scheme 1. Reactivity and Selectivity of the Present Silylzincation

reflux) in moderate yield (0–58%). In the competitive reaction of terminal and internal acetylenes in 1,5-decadiyne (**6**) using SiBNOL-Zn-ate, silylzincation at the terminal alkyne proceeded with more than 99% selectivity.

We have also demonstrated, as shown in Scheme 2, that the resultant dianion-type vinylzincate intermediate (**2a**) can be utilized as a vinyl anion equivalent and shows the chemical reactivities characteristic of an organozinc species. For instance, the intermediate **2a**, generated by the silylzincation of 1-octyne (**1a**) using SiBNOL-Zn-ate, was treated with D_2O or allyl bromide to give the corresponding deuterated or allylated olefins in 90 and 94% yields, respectively. The vinylzincate intermediate **2a** also undergoes copper- and palladium-catalyzed C–C bond-forming reactions in high yields and with high regioselectivities.

In conclusion, a dianion-type Zn(II) ate complex (SiBNOL-Zn-ate) ligating DMPS, ^tBu, and biphenoxo groups promotes chemo-

Scheme 2. Electrophilic Trapping of the Intermediate (**2a**) Generated in Situ by Silylzincation of 1-Octyne (**1a**) Using SiBNOL-Zn-ate

and regioselective silylzincation reaction of terminal alkynes at room temperature. The method provides a simple and direct route for the synthesis of regiocontrolled trisubstituted olefins from various functionalized terminal alkyne precursors. Efforts to expand the reaction scope and to elucidate the reaction pathway with the help of theoretical and spectroscopic studies are in progress in our laboratory.

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Supporting Information Available: Experimental procedures and characterizations (PDF). This material is available free of charge via the Internet at <http://pubs.acs.org>.

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