First Example of Alkynyliodonium Tosylates coupling with 1,1-Bimetalloalkenes of Selenium and Zirconium†

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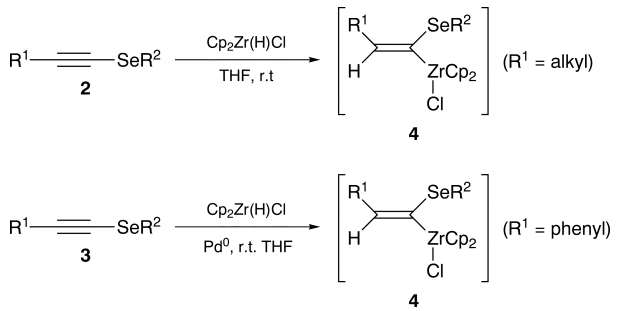
Hydrozirconation of internal acetylenic selenides afforded 1,1-bimetalloalkenes, (*E*)-α-selanylvinylzirconium, which can cross-couple with alkynyliodonium tosylates directly in the presence of $Pd(PPh_3)_4$ as the catalyst.

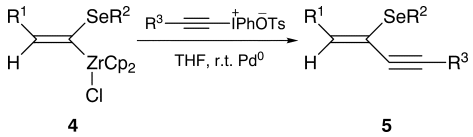
The stereoselective synthesis of conjugated enynes is of great importance in organic chemistry because of many natural compounds containing their structural skeletons.[1] A number of methods for the preparation of conjugated enynes have been previously reported, particularly transition-metal-catalyzed processes.[1] Coupling of stereodefined alkenyl metallic compounds include vinylboron,[2] vinylcopper,[3,4] vinylzinc,[5,6] vinylaluminium[7] or vinylmagnesium reagents[8] with haloalkynes. Recently, the synthesis of conjugated functionalized enynes have received more attention. Although various methods for the synthesis of vinylic selenides have been studied intensively,[9] the synthesis of 1,3-enynylselenides has been little explored.[10] In a previous paper, we reported the coupling of diaryliodonium salts and vinylzirconium compounds in the presence of $Pd(PPh_3)_4$,[11] compared with the cross-coupling of vinylzirconium compounds with arylhalides, which has the advantages of lower reaction time and mild reaction conditions. As an extension of our studies, herein we report the stereoselective formation of selanyl-substituted 1,3-enynes *via* a new carbon–carbon bond-forming reaction, involving the coupling of alkynyliodonium tosylates **1** and (*E*)-α-selanylvinylic zirconium compounds **4** in the presence of $Pd(PPh_3)_4$.

Alkynyliodonium tosylates **1** are readily available in reasonable yields by interaction of Koser's reagent, PhI(OH)OTs, with terminal alkynes.[12] (*E*)-α-Selanylvinylic zirconium compounds **4** are readily made by hydrozirconation of internal acetylenic selenides **2**, **3**; hydrozirconation of phenylacetylenic selenides **3** can not be directly performed even over extended times or at a raised temperature, however, in the presence of 5% mmol $Pd(PPh_3)_4$, **3** can react with $Cp_2Zr(H)Cl$ rapidly in about 1 h at room temperature (Scheme 1). Alkynyliodonium tosylate **1** was added to a mixture of (*E*)-α-selanylvinylic zirconium compound **4** and 5% mmol $Pd(PPh_3)_4$ in THF and stirred for about 3 h, which resulted in the stereoselective synthesis of conjugated enynylselenides **5** (Scheme 2).

As the data in Table 1 show, this method affords a variety of 1,3-enynylselenides stereoselectively in good

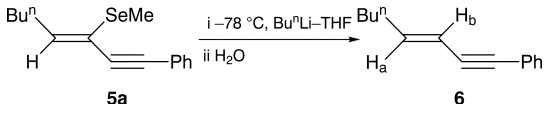


Scheme 1



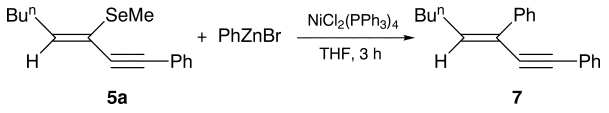
Scheme 2

yields, and more importantly, the reaction can be performed at room temperature in about 2 h. The configuration of selenoenyne **5a** could be confirmed from compound **6** which was obtained by treatment of **5a** with *n*-butyllithium in THF followed by hydrolysis; the reaction occurs stereoselectively (Scheme 3).[13] Particularly diagnostic for the stereochemistry of **6** was the coupling constant between the vicinal protons H_a and H_b which show a typical value of J_{HH} of 16 Hz which is consistent with an *E* configuration.



Scheme 3

Conjugated enynylselenides are important synthetic intermediates and are effective precursors for synthesizing conjugated enynes, for example, **5a** at room temperature in THF can be coupled with PhZnBr in the presence of 5 mmol% $NiCl_2(PPh_3)_2$ for 3 h to give **7** in an isolated yield of 60% (Scheme 4).



Scheme 4

In summary, we have combined vinylzirconium compounds and hypervalent iodine salts to synthesize conjugated enynes. Compared to other methods that have been reported, this method has the advantages of mild conditions, simple procedure and lower reaction time.

Experimental

^{1}H NMR spectra were recorded on an AZ-300 MHz with TMS as internal standard. Mass spectra were determined using a Finigan 8230 mass spectrometer. IR spectra were obtained in neat capillary cells on a Shimadzu IR-408 instrument. The reactions were carried out in pre-dried glassware (150 °C, 4 h) and cooled under a stream of dry nitrogen. All solvents were dried, deoxygenated and redistilled before use.

General Procedure for the Synthesis of 1,3-*Enynylselenides* **5a**–**f**.— To a freshly prepared suspension of $Cp_2Zr(H)Cl$ (2 mmol) in THF (15 ml) at r.t. was injected acetylenic selenides **2** (2 mmol) in THF (2 ml) [for added phenylacetylenic selenides **3**, $Pd(PPh_3)_4$ (2 × 5% mmol) must be added simultaneously]. The reaction mixture was stirred for *ca.* 30 min and turned green, then $Pd(PPh_3)_4$ (2 × 5% mmol) and alkynyliodonium tosylates **1** (2 mmol) in THF (2 ml) were added to the solution at r.t. and stirred for 2 h. The

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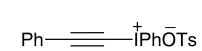
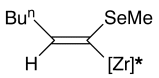
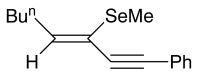
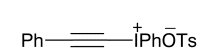
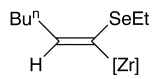
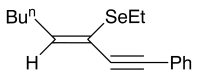
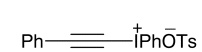
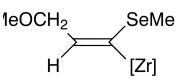
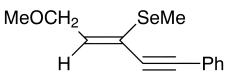
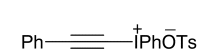
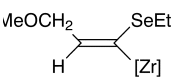
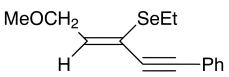
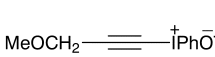
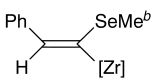
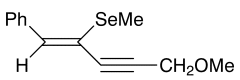
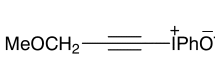
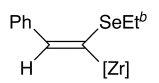
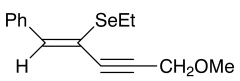
Table 1 Alkynyliodonium/(*E*)-α-selanylvinylzirconium compound couplings

Entry	Alkynyliodonium salt	(*E*)-α-Selanylvinylzirconium	Enzyne	Yield[a] (%)
5a				80
5b				75
5c				85
5d				83
5e				75
5f				70

[a]Isolated yield. [b]In the presence of $Pd(PPh_3)_4$.

product was washed with saturated aq. NH_4Cl (10 ml) then extracted into diethyl ether, dried with $MgSO_4$, filtered and concentrated *in vacuo*. The residue was purified by flash chromatography on a 3 ft × 1 in column with light petroleum (bp 30–60 °C) eluent to give **5a**–**f**.

5a: ^{1}H NMR δ 7.70–7.20 (m, 5H), 6.10 (t, *J* 6.6 Hz, 1H), 2.18 (s, 3H), 1.96–2.34 (m, 2H), 1.14–1.49 (m, 4H), 0.81 (t, 3H). MS: *m*/*z* 278 (M^++1) (Found: C, 64.93; H, 6.44. $C_{15}H_{18}Se$ requires C, 64.98; H, 6.54%).

5b: ^{1}H NMR δ 7.69–7.18 (m, 5H), 6.08 (t, *J* 6.6 Hz, 1H), 2.53 (q, 2H), 1.94–2.30 (m, 2H), 1.47 (t, 3H), 1.12–1.50 (m, 4H), 0.79 (t, 3H). MS: *m*/*z* 292 (M^++1) (Found: C, 65.65; H, 6.46. $C_{16}H_{20}Se$ requires C, 65.97; H, 6.92%).

5c: ^{1}H NMR δ 7.65–7.10 (m, 5H), 6.10 (t, *J* 6.7 Hz, 2H), 3.80 (d, 2H), 3.24 (s, 3H), 2.17 (s, 3H), MS: *m*/*z* 265 (M^++1) (Found: C, 58.53; H, 5.02. $C_{13}H_{14}SeO$ requires C, 58.87; H, 5.32%).

5d: ^{1}H NMR δ 7.66–7.12 (m, 5H), 6.12 (t, *J* 6.7 Hz, 1H), 3.83 (d, 2H), 3.25 (s, 3H), 2.55 (q, 2H), 1.52 (t, 3H). MS: *m*/*z* 279 (M^++1) (Found: C, 59.74; H, 5.35. $C_{14}H_{16}SeO$ requires C, 60.22; H, 5.78%).

5e: ^{1}H NMR δ 7.50–7.0 (m, 5H), 6.78 (s, 1H), 4.12 (s, 2H), 3.29 (s, 3H), 2.15 (s, 3H), MS: *m*/*z* 266 (M^++1) (Found: C, 58.40; H, 4.86. $C_{13}H_{14}SeO$ requires C, 58.88; H, 5.32%).

5f: ^{1}H NMR δ 7.49–7.02 (m, 5H), 6.77 (s, 1H), 4.14 (s, 2H), 3.30 (s, 3H), 2.65 (q, 2H), 1.49 (t, 3H). MS: *m*/*z* 280 (M^++1) (Found: C, 59.82; H, 5.40. $C_{14}H_{16}SeO$ requires C, 60.22; H, 5.78%).

Addition of Bu^{n}Li to 1,3-*Enynylselenide* **5a** → *Enyne* **6**.—BuLi (1.6 M hexane solution, 1.1 mmol) was added to a THF (5.0 ml) solution of **5a** (1.0 mmol) at −78 °C. After stirring for 30 min, the mixture was hydrolyzed with saturated aq. NH_4Cl and extracted with CH_2Cl_2 (2 × 10 ml). The organic extract was dried with $MgSO_4$, filtered and concentrated *in vacuo*. The residue was purified by column chromatography over silica gel (hexane as eluent) to give **6** (yield: 90%). ^{1}H NMR δ 7.24 (m, 5H), 6.17 (dt, 1H, *J* 6.5 and 16 Hz), 5.62 (d, 1H, *J* 16 Hz), 2.15 (q, 2H), 1.20–2.05 (m, 4H), 0.93 (t, 3H).

General Procedure for the Synthesis of **7**.—PhZnBr (1.0 mmol) in THF (3.0 ml) was added to a THF (5.0 ml) solution of selenoenyne **5a** (1.0 mmol) and $NiCl_2(PPh_3)_2$ (1.0 × 5% mmol) at r.t. After stirring for 3 h, the mixture was washed with saturated aq. NH_4Cl. The product was extracted with hexane and dried over $MgSO_4$, filtered and concentrated *in vacuo*. The residue was purified by flash chromatography on a 3 ft × 1 in column with hexane as eluent to give **8**. ^{1}H NMR δ 7.71–7.01 (m, 10H), 6.30 (t, 1H, *J* 6.8 Hz), 2.45–2.10 (m, 2H), 1.43–1.22 (m, 4H), 0.84 (t, 3H).

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