Unusual Cleavage of the Enolsilane C-O Bond: Transformation of 2-Silyloxy-1,3-dienes into 1,3-Dienyl-2-zirconium Compounds and their Cross-Coupling Reactions

Benjamin Ganchegui, Philippe Bertus, Jan Szymoniak*

Réactions Sélectives et Applications, CNRS and Université de Reims, 51687 Reims Cedex 2, France Fax +33-3-26913166; E-mail: jan.szymoniak@univ-reims.fr

Received 6 October 2000

Abstract: Aryl enolsilanes and 2-silyloxy-1,3-dienes react with zirconocene to give alkenylzirconium, and novel 1-methylene-2-propenylzirconium compounds which can be used as 2-dienylation reagents. Thus, one-pot coupling of 4-phenyl-1,3-butadienyl-2-zirconocene (**2d**) with a range of electrophiles including aryl, alkynyl, allyl halides, bromine, iodine and a Michael acceptor occurs regioselectively at the C-2 position in the presence of Pd or Cu catalysts.

Key words: silyloxydienes, zirconium, dienylzirconocenes, crosscoupling

The cross-coupling reactions of vinylmetals with electrophiles constitutes henceforth a powerful strategy for carbon-carbon bond formation.¹ In this matter, alkenylzirconocenes are very attractive reagents, since they can be readily generated in situ from alkynes via hydrozirconation,² and further transmetallated to various metals such as Al, B, Cu, Pd, Ni, Sn and Zn.³ This method is primarily limited, however, by the unique regioselectivity of hydrozirconation, invariably placing Zr at the least hindered (terminal) position. The oxidative addition reaction of alkenyl derivatives to zirconocene ('Cp₂Zr') appears as an interesting alternative. Yet, in contrast to the well known oxidative addition of allyl ethers or acetals to 'Cp₂Zr',⁴ the reactions that involve alkenyl substrates are restricted to a few recent examples including vinyl chlorides, vinyl bromides, tosylates and/or fluorides and phenyl vinyl ether (Scheme 1).⁵





Among numerous reactions of enolsilanes,⁶ the most common involve the O-Si bond breaking to generate specific enolate anions. Here we report an unprecedented, zirconium induced, C-O bond breaking in some enol- and dienolsilanes to provide alkenyl- and novel 1-methylene-2-propenyl-zirconocene derivatives. 1-Zirconated 1,3-dienes thus produced in situ, were further demonstrated to be effective components in several different cross-coupling reactions. While studying the reactivity of zirconocene-coordinated silyloxy azadienes,⁷ we performed some reactions with the nitrogen-free analogs and simpler enolsilanes. We were surprised to find that oxidative addition reactions occurred starting from aryl enolsilanes, to provide the corresponding vinylzirconium compounds. Thus, treatment of naphthyl enolsilane **1a** with the zirconocene equivalent ('Cp₂Zr')⁸ in THF at room temperature for 20 h, followed by quenching with D₂O, afforded the deuterated alkene **3a**.⁹ By heating at reflux, the reaction was completed within only 2 h. As can be seen from Table (entry 1) similar yields (68% and 72%) were obtained in these cases. The formation of the vinylzirconium intermediate **2a** was further evidenced by a one-pot Pd(0)-catalyzed reaction with 4-iodotoluene to produce the cross-coupling product

 Table
 Oxidative Addition of Enolsilanes 1a-c and Silyloxydienes 1d-e to Zirconocene, followed by Deuterolysis.^{a,b}

Cp₂7

Substrate (1)

1a QSiMe₃

1b

1c

1d

1e

C₇H₁₅

OSiMe

OSiMe₃

QSiMe₃

Nr

OSiMe₂

2a-e

Product (3)

3d

За-е

Yield [%]

72 ^{*a*,*c*}

 $(68)^{b,c}$

80 ^{*a,d*}

0

76 ^{a,c}

65 ^{*a*,*c*}

SiMe-

1a-e

Entry

1

2

3

4

5



C₇H₁

123

4 (Scheme 2). The oxidative addition also took place starting from acetophenone-derived enolsilane **1b** (Table, entry 2). In contrast to the reactions employing aryl enolsilanes (**1a**,**b**), no reaction occurred from the alkyl enolsilane **1c** (entry 3), the substrate was entirely recovered. Neither prolonged reaction time nor warming of the reaction mixture produced the expected vinylzirconation compound. The presence of a neighbouring aryl group must have allowed the β -elimination of OSiMe₃ from the intermediary zirconacyclopropane.



Thereafter, we used silvloxydienes 1d,e as substrates, and noticed that, in this case, the oxidative addition reactions did not proceed at room temperature, but could be achieved at reflux within 2 hours. The formation of dienyl-2-zircononium compounds 2d,e was evidenced by deuterolysis. When the reaction mixtures were treated with D₂O, 2-deuterated dienes 3d,e (>95% D incorporation) were isolated as the only products (Table, entries 4,5). Moreover, the ¹H NMR spectrum of **2d** in $C_6 D_6^{10}$ showed singlet signals at δ 5.90 (10 H) and 0.10 (9 H), assignable to Cp and OSiMe₃ protons, respectively. Its ¹³C NMR spectrum revealed the Cp carbons at δ 111.5 and a signal at δ 191.2, assignable to an alkenyl carbon attached to zirconium.^{5a,11} Thus, similarly to the aryl, also the alkenyl group on enolsilane allowed the reaction to occur, even if much more drastic conditions were needed.



Scheme 3

Whereas 1-zirconated 1,3-dienyl compounds could be readily obtained by hydrozirconation of the conjugated enynes,¹² there is no report on the 2-zirconated 1,3-dienyl compounds, to the best of our knowledge. We thought that the dienylzirconium compounds such as 2d or 2e might be useful reagents to perform dienylation reactions, specifically at the C-2 position.¹³ We were pleased to find that these compounds underwent various cross-coupling reactions. Representative examples involving 2d are shown in Scheme 3. The reactions were carried out in one pot via transmetallation, by analogy with the reactions involving alkenylzirconium compounds.^{3,14} A complete regioselectivity at C-2 and moderate to good yields were observed.9 Starting from the preformed 2d, the reaction with p-tolyl iodide proceeded smoothly in THF at reflux for 3 h in the presence of the palladium (0) catalyst (5% mol) and zinc chloride to afford **5** (60% isolated yield from **1d**).^{9,10} The coupling reaction with 1-iodoheptyne was performed in a similar fashion to produce the dienyne 6. The Cu-catalyzed allylation led to the triene 7 as expected. Reactions of 2d with N-bromosuccinimide and I₂ provided 2-bromoand 2-iodo-1,3-dienes, 8 and 9, respectively. It is worthy to note that methods for preparing 2-halogeno-1,3-dienes are rare.¹⁵ Finally, the Cu(I)-mediated conjugated addition of 2d to methyl vinyl ketone was achieved to give the dienvlketone **10**.

In summary, the oxidative addition reactions of aryl enolsilanes and 2-silyloxydienes to zirconocene produced the corresponding alkenyl- and dienyl-2-zirconocenes. The novel dienylzirconium compounds, which are not available by hydrozirconation, have been demonstrated to be effective 2-dienylation reagents. Their successive C-C bond-forming reactions with a variety of coupling components were achieved in one-pot through transmetallation. The method thus provides a two-step conversion of α , β -enones into various 2-dienyl derivatives. We currently explore the synthetic potential of these new transformations.

References and Notes

- Diederich, F.; Stang, P. J. Metal-Catalyzed Cross-Coupling Reactions, Wiley-VCH, Weinheim, 1998.
- (2) (a) Schwartz, J.; Labinger, J. A. Angew. Chem. Int. Ed. Engl. 1976, 15, 333. (b) Labinger, J. A. Comprehensive Organic Synthesis, Vol. 8, Trost, B. M.; Fleming, I Eds., Pergamon Press, Oxford, 1991.
- (3) Wipf, P.; Heike, J. Tetrahedron 1996, 52, 12853.
- (4) (a) Ito, H.; Motoki, Y.; Taguchi, T.; Hanzawa, Y. J. Am. Chem. Soc. 1993, 115, 8835. (b) Negishi, E.; Takahashi, T. Bull. Chem. Soc. Jpn. 1998, 71, 755 and references therein.
- (5) (a) Takahashi, T.; Kotora, M.; Fischer, R.; Nishihara, Y.; Nakajima, K. J. Am. Chem. Soc. 1995, 117, 11039.
 (b) Ichikawa, J.; Fujiwara, M.; Nawata, H.; Okauchi, T.; Minami, T. Tetrahedron Lett. 1996, 37, 8799. (c) Fujiwara, M.; Ichikawa, J.; Okauchi, T.; Minami, T. Tetrahedron Lett. 1999, 40, 7261.
- (6) Colvin, E. W. Silicon in Organic Synthesis, Krieger, R. E. Publishing Company, Malabar, Florida, 1985.

- (7) (a) Gandon, V.; Bertus, P.; Szymoniak, J. *Tetrahedron Lett.* 2000, 41, 3053. (b) Gandon, V.; Bertus, P.; Szymoniak, J. *Tetrahedron* 2000, 56, 4467.
- (8) For reviews of "Cp₂Zr" chemistry, see ref. 4b and (a) Negishi, E.; Kondakov, D. Y. *Chem. Soc. Rev.* **1996**, *26*, 417.
 (b) Negishi, E.; Takahashi, T. *Acc. Chem. Res.* **1994**, *27*, 124.
- (9) All products were fully characterized by ¹H, ¹³C NMR and MS spectroscopy.
- (10) Typical Procedure (1d → 2d → 5): To a solution of Cp₂ZrCl₂ (1 mmol) in THF (4 mL) was added *n*-BuLi (2 mmol, 2.5 M in hexanes) at -78 °C. After stirring for 1 h at -78 °C the silyloxydiene 1d (1 mmol) in THF (2 mL) was added via syringe. After warming up to r.t. (15 min) the reaction mixture was refluxed for 2 h. At this stage, isolation of the dienylzirconocene 2d (I) or a direct cross-coupling step (II) might follow:

(I) After evaporation of the solvent, toluene (3 mL) was added and the inorganic salts were filtered off. Washing with pentane (2 mL) afforded **2d**, 95% pure by ¹H NMR. Spectral data for **2d**: ¹H NMR (250 MHz, C_6D_6) δ 0.10 (s, 9H), 5.50 (d,

 $J = 3.8\text{Hz}, 1\text{H}), 5.90 (s, 10\text{H}), 6.12 (d, J = 3.8\text{Hz}, 1\text{H}), 6.22 (d, J = 15.6\text{Hz}, 1\text{H}), 6.90-7.50 (m, 6\text{H}); {}^{13}\text{C} \text{ NMR} (62.5 \text{ MHz}, C_6\text{D}_6): \delta 2.1 (\text{CH}_3), 111.5 (\text{CH}), 124.5 (\text{CH}_2), 126.2 (\text{CH}), 126.6 (\text{CH}), 128.0 (\text{CH}), 128.6 (\text{CH}), 139.4 (\text{C}), 143.8 (\text{CH}), 191.2 (\text{C}).$

(II) Pd(PPh₃)₄ (0.05 mmol), ZnCl₂ (1.3 mmol) and *p*-iodotoluene (1 mmol) were added at r.t. and the reaction mixture refluxed for 3 h. The mixture was treated with 1 M HCl (2mL) for 30 min and extracted with ether (3×15 mL). The organic extracts were dried, filtered and concentrated, and the residue was purified by flash chromatography (petroleum ether) to give **5** (70%) as colorless syrup.

- (11) (a) Takahashi, T.; Suzuki, N.; Kageyama, M.; Kondakov, D. Y.; Hara, R. *Tetrahedron Lett.* **1993**, *34*, 4811. (b) Takahashi, T.; Kondakov, D. Y.; Xi, Z.; Suzuki, N. J. Am. Chem. Soc. **1995**, *117*, 5871.
- (12) Fryzuk, M. D.; Bates, G. S.; Stone, C. *Tetrahedron Lett.* **1986**, 27, 1537.
- (13) A few 2-metallated buta-1,3-dienes (M = Mg, Li, Sn, Zn) were employed as nucleophilic reagents, often giving low yields and/or regioselectivities, see Mg: (a) Nunomoto, S.; Yamashita. Y. J. Org. Chem. 1979, 44, 4788. (b) Shea, K. J.; Pham. P. Q. Tetrahedron Lett. 1983, 24, 1003. Li: (c) Wada, E.; Kanemasa, S.; Fujiwara, I.; Tsuge. O. Bull. Chem. Soc. Jpn. 1985, 58, 1942. (d) Bloch, R.; Chaptal-Gradoz, N.; J. Org. Chem. 1994, 59, 4162. Sn: (e) Luo, M.; Iwabuchi, Y.; Hatakeyama, S. Synlett 1999, 7, 1109. Zn: (f) Matsubara, S.; Ukai, K.; Toda, N.; Utimoto, K.; Oshima, K. Synlett 2000, 7, 995.
- (14) (a) Negishi, E.; Okukado, N.; King. A. O.; Van Horn, D. E.; Spiegel, B. I. J. Am. Chem. Soc. 1978, 100, 2254. (b) Lipshutz, B. H.; Sengupta, S. Org. React. 1992, 41, 135. (c) Takahashi, T.; Kotora, M. Kasai, K.; Suzuki, N. Tetrahedron Lett. 1994, 35, 5685. (d) Hara, R.; Liu, Y.; Sun, W-H.; Takahashi, T. Tetrahedron Lett. 1997, 38, 4103.
- (15) (a) Mitani, M.; Kobayashi, Y.; Koyama, K. J. Chem. Soc., Perkin Trans. 1 1995, 653. (b) Okamoto, S.; Sato. H.; Sato, F. Tetrahedron Lett. 1996, 37, 8865. (c) Brandsma, L.; Vasilevsky, S. F.; Verkruijsse, H. D. Application of Transition Metal Catalysts in Organic Synthesis, Springer, Berlin, 1998, p. 42.

Article Identifier:

1437-2096,E;2001,0,01,0123,0125,ftx,en;G21800ST.pdf

There is an erratum or addendum to this paper. Please check www.thieme.de/chemistry/synthesis/index.html.