

Letter

# Ruthenium-catalyzed addition of olefinic C–H bonds in conjugate enones to acetylenes to give conjugate dienones

Fumitoshi Kakiuchi, Tomohiro Uetsuhara, Yasuo Tanaka,  
Naoto Chatani, Shinji Murai\*

*Faculty of Engineering, Department of Applied Chemistry, Osaka University, Suita, Osaka 565-0871, Japan*

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## Abstract

Addition of a  $\beta$  C–H bond in conjugate enones to internal acetylenes to give conjugate dienones proceeded with the aid of  $\text{RuH}_2(\text{CO})(\text{PPh}_3)_3$  as the catalyst. The reaction of pivaloylcyclohexene with diphenylacetylene gave the corresponding dienone in high yield. Acylpyranes can also be used in these olefinic C–H/acetylene coupling reactions. Phenyltrimethylsilylacetylene is also able to serve as a C–H bond acceptor. © 2002 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

A recent, popular protocol for the alkylation of arenes, which involves chelation-assisted C–H/olefin coupling using transition metal catalysts, has opened new opportunities for the regioselective alkylation of arenes (for a recent review, see [1]). In our ongoing studies of the ruthenium-catalyzed addition of C–H bonds in arenes having a directing group, e.g., ketone carbonyl, ester carbonyl, and imino groups, we have investigated additions to olefins via C–H bond cleavage [2–6].<sup>1</sup> When, in place of aromatic compounds, olefinic compounds such as  $\alpha,\beta$ -unsaturated ketones

[4] and esters [7] were used in this type of coupling reaction, alkylation took place exclusively at the C–H bond in a  $\beta$ -position to the directing group. In the case of the reaction with acetylenes, the vinylation of arenes occurred to give the corresponding styrene derivatives [5,8,9]. We now wish to report that acetylenes can be also employed in ruthenium-catalyzed reactions of conjugate enones. The vinylation of the enone gives  $\alpha,\beta$ ;  $\gamma,\delta$ -unsaturated enones, which represent versatile intermediates in organic synthesis [10–12]. In this letter, we describe a highly selective vinylation of  $\alpha,\beta$ -conjugate enones with acetylenes with the aid of ruthenium complexes as catalysts.

## 2. Experimental

A 10 ml, two necked, round-bottomed flask equipped with a reflux condenser, a nitrogen inlet with a gas bubbler, a magnetic stirring bar, and an inlet tube

\* Corresponding author. Tel.: +81-6-6879-7397;

fax: +81-6-6879-7396.

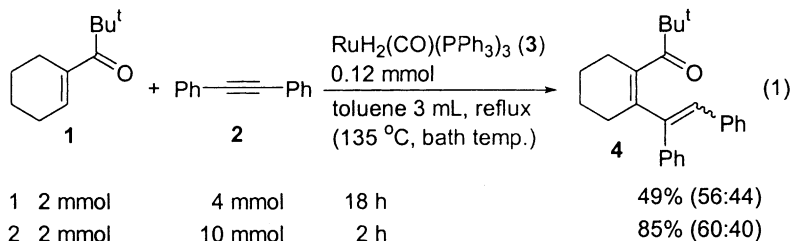
*E-mail address:* murai@chem.eng.osaka-u.ac.jp (S. Murai).

<sup>1</sup> For first paper in this series, see [2]; for olefinic C–H/olefin coupling, see [4]; for aromatic C–H/acetylene coupling, see [5] and for the latest paper in this series, see [6].

sealed with a rubber septum, was flushed with dry nitrogen, and the apparatus was then flame-dried under a stream of dry nitrogen. In the flask,  $\text{RuH}_2(\text{CO})(\text{PPh}_3)_3$  (0.12 mmol) was placed under nitrogen. To the flask 3 ml of toluene, an enone (2 mmol), and an acetylene (10 mmol) were added. The mixture was heated under vigorous reflux (135 °C, oil bath temperature) with stirring. After heating for an appropriate period, the mixture was allowed to cool to room temperature, and toluene was removed by rotary evaporation. The resulting dark-brown residue was then purified by silica gel column chromatography.

### 3. Results and discussion

A reaction of 1-pivaloylcyclohexene (**1**) with diphenylacetylene (**2**) was carried out in the presence of  $\text{RuH}_2(\text{CO})(\text{PPh}_3)_3$  (**3**) as a catalyst for 18 h under refluxing conditions. The vinylation of the enone, giving the conjugate dienone **4** in 49% yield, proceeded exclusively at the position  $\beta$  to the ketone carbonyl group. The use of five equivalents of the acetylene **2** increased the yield of **4** to 85% (2 h). In both the cases, the *E* and *Z* isomerization at the 1,2-diphenylvinyl moiety occurred during the reaction.



We examined the present olefinic C–H/olefin coupling using various conjugate enones. However, only a limited number of cyclic enones showed the catalytic activity. Some other results are listed in Table 1. In addition to a cyclohexene derivative **1**, dihydropyran derivatives were also applicable to this olefinic C–H/acetylene coupling. The reaction of 5-acetyl-3,4-dihydro-2*H*-pyran (**5**) with the acetylene **2** afforded the corresponding coupling product **6** in 56% yield with a high degree of stereoselectivity (*E*:*Z* = 93:7) (run 1). The reactivity of the enone **5** is nearly the same as **1**. Interestingly, 6-pivaloyl-3,4-dihydro-2*H*-pyran **7** showed a higher

reactivity compared to **5**. The coupling product **8** was obtained in 71% yield after 1 h (run 2). An unsymmetrically substituted internal acetylene such as phenyl(trimethylsilyl)acetylene (**9**) can also be used (run 3). The highly congested conjugate dienone **10** was obtained in high yield (96%) with high stereoselectivity (*E*:*Z* = 94:6). In this case, the formation of two regioisomers is possible, but the C–C bond formation took place in a regiospecific manner (run 3). The same regioselectivity was previously observed when the silylacetylene **9** was used for the reaction of aromatic ketones [5].

However, other acetylenes such as 4-octyne, diethyl acetylenedicarboxylate, bis(trimethylsilyl)acetylene, 1-trimethylsilyl-1-propyne, and 1-phenyl-1-propyne proved to be unreactive under the reaction conditions shown in Table 1.

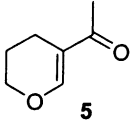
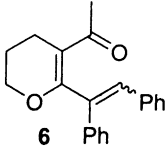
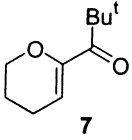
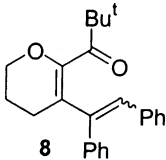
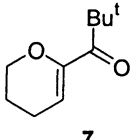
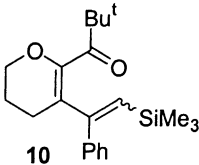
The mechanism of the present olefinic C–H/acetylene coupling has not been clarified. We propose a mechanism of the present coupling reaction, which is analogue to the mechanism with respect to the  $\text{RuH}_2(\text{CO})(\text{PPh}_3)_3$ -catalyzed reaction of aromatic ketones with olefins [3,13,14]. A possible, plausible mechanism is shown in Scheme 1.

The reaction appears to be initiated by C–H bond cleavage leading to the five-membered metalacycle

**B**. The coordination of acetylene to intermediate **B**, followed by the addition of the Ru–H bond to the acetylene, results in the formation of the aryl(vinyl)ruthenium intermediate **D**. The reductive elimination, leading to C–C bond formation, affords the corresponding coupling product and regenerates the catalytic active species.

In summary, we document herein that the  $\text{RuH}_2(\text{CO})(\text{PPh}_3)_3$ -catalyzed addition of C–H bonds in conjugate enones to acetylenes takes place to give the corresponding conjugate dienones in good to high yields. Since C–C bond formation occurred exclusively

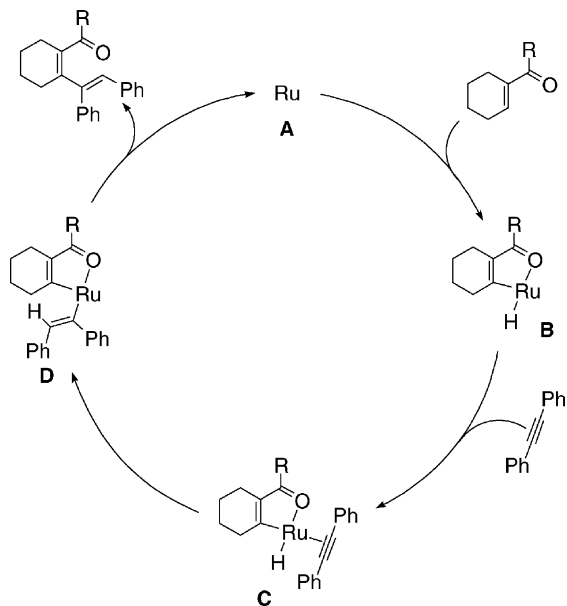
Table 1  
 RuH<sub>2</sub>(CO)(PPh<sub>3</sub>)<sub>3</sub>-catalyzed addition of olefinic C–H bond to acetylenes<sup>a</sup>

Run	Enone	Acetylene	Time (h)	Product	Yield <sup>b</sup> ( <i>E</i> : <i>Z</i> ratio) <sup>c</sup>
1		2	15		56% ( <i>E</i> : <i>Z</i> = 93:7)
2		2	1		71% ( <i>E</i> : <i>Z</i> = 76:24)
3		9	1		96% ( <i>E</i> : <i>Z</i> = 94:6)

<sup>a</sup> Reaction conditions: enone (2 mmol), acetylene (4 mmol), RuH<sub>2</sub>(CO)(PPh<sub>3</sub>)<sub>3</sub> (0.12 mmol, toluene 3 ml; reflux (135 °C, oil bath temperature)).

<sup>b</sup> Isolated yield.

<sup>c</sup> Determined by the <sup>1</sup>H NMR spectra.



Scheme 1. Proposed reaction pathway for olefinic C–H/acetylene coupling.

at the  $\beta$  position of the ketone carbonyl group, chelation-assistance appears to be important for the olefinic C–H/acetylene coupling as we have previously reported for the ruthenium-catalyzed aromatic C–H/olefin coupling [3,13,14]. Additional details on the scope of this process will be the topics of future investigations in our laboratories.

## References

- [1] F. Kakiuchi, S. Murai, in: S. Murai (Ed.), Topics in Organometallic Chemistry, Vol. 3, Springer, Berlin, 1999, pp. 47–79.
- [2] S. Murai, F. Kakiuchi, S. Sekine, Y. Tanaka, A. Kamatani, M. Sonoda, N. Chatani, Nature 366 (1993) 529.
- [3] F. Kakiuchi, S. Sekine, Y. Tanaka, A. Kamatani, M. Sonoda, N. Chatani, S. Murai, Bull. Chem. Soc. Jpn. 68 (1995) 62.
- [4] F. Kakiuchi, Y. Tanaka, T. Sato, N. Chatani, S. Murai, Chem. Lett. (1995) 679.
- [5] F. Kakiuchi, Y. Yamamoto, N. Chatani, S. Murai, Chem. Lett. (1995) 681.
- [6] F. Kakiuchi, H. Ohtaki, M. Sonoda, N. Chatani, S. Murai, Chem. Lett. (2001) 918.

- [7] B.M. Trost, K. Imi, I.W. Davies, *J. Am. Chem. Soc.* 117 (1995) 5371.
- [8] P. Hong, B.-R. Cho, H. Yamazaki, *Chem. Lett.* (1979) 339.
- [9] G. Halbritter, F. Knoch, A. Wolski, H. Kisch, *Angew. Chem. Int. Ed. Engl.* 33 (1994) 1603.
- [10] J.V. Allen, S. Bergeron, M.J. Griffiths, S. Mukherjee, S.M. Roberts, N.M. Williamson, L.E. Wu, *J. Chem. Soc. Perkin Trans. 1* (1998) 3171.
- [11] G. Majetich, J. Fang, *Tetrahedron Lett.* 39 (1998) 8381.
- [12] M. Ihara, S. Suzuki, N. Taniguchi, K. Fukumoto, *Synlett* (1993) 435, and references cited therein.
- [13] T. Matsubara, N. Koga, D.G. Musaev, K. Morokuma, *J. Am. Chem. Soc.* 120 (1998) 12692.
- [14] T. Matsubara, N. Koga, D.G. Musaev, K. Morokuma, *Organometallics* 19 (2000) 2318.