

# Dicobalt Octacarbonyl-Catalyzed Tandem [2 + 2 + 1] and [2 + 2 + 2] Cycloaddition Reaction of Diynes with Two Phenylacetylenes under CO

Seung Uk Son, Dai Seung Choi, and Young Keun Chung\*

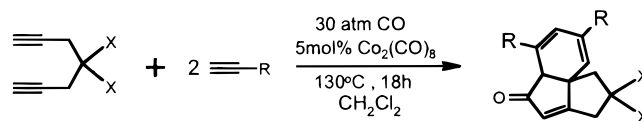
School of Chemistry and Center for Molecular Catalysis, Seoul National University, Seoul 151-742, Korea

Sueg-Geun Lee

Korea Research Institute of Chemical Technology, PO Box 9, Daejeon 305-606, Korea  
ykchung@plaza.snu.ac.kr

Received April 25, 2000

## ABSTRACT



Novel 5-5-6 tricyclic compounds containing cyclopentenone have been constructed by the dicobalt octacarbonyl catalyzed tandem [2 + 2 + 1] and [2 + 2 + 2] cycloaddition reaction between a diene and two phenylacetylene under CO pressure.

Transition metal catalyzed cycloadditions of unsaturated substrates are useful reactions for the construction of complex cyclic compounds.<sup>1</sup> Among them, the Pauson–Khand cycloaddition (the [2 + 2 + 1] cycloaddition of alkyne, alkene, and carbon monoxide)<sup>2</sup> has attracted much attention for the preparation of a variety of cyclopentenone systems. However, cyclopentadienone has played no role in the five-membered ring construction due to its inherent instability and tendency to undergo dimerization.<sup>3</sup> One of the potentially useful reactions is the use of the high reactivity of cyclopentadienones:<sup>4</sup> a transition metal catalyzed [2 + 2 + 2]

cycloaddition reaction of the olefinic double bond of cyclopentadienone with two alkynes. However, it seems to be very difficult to control the regioselectivity. No successful examples of catalytic tandem [2 + 2 + 1] and [2 + 2 + 2] cycloaddition reaction of diene with alkynes have been reported even though there has been much research<sup>5</sup> in the [2 + 2 + 2] cycloaddition reaction of a diene with an alkyne or alkene. Now we report a facile construction of novel tricyclic compounds by the dicobalt octacarbonyl catalyzed tandem [2 + 2 + 1] and [2 + 2 + 2] cycloaddition reaction between a diene and two phenylacetylenes under CO pressure.

Treatment of **1** and **2** equiv phenylacetylene with Co<sub>2</sub>(CO)<sub>8</sub> (5 mol %) at 130 °C under 30 atm CO for 18 h afforded a tricyclic product **1A** in 68% yield (eq 1).<sup>6</sup>

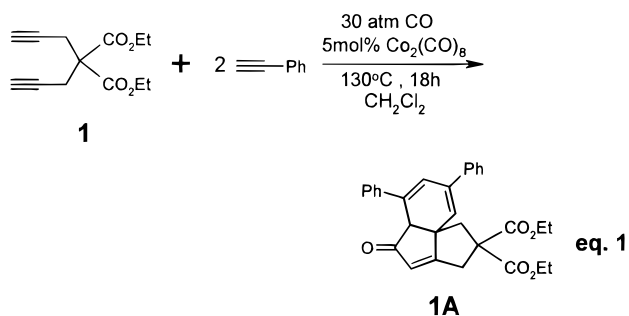
(1) Ojima, I.; Tzamarioudaki, M.; Li, Z.; Donovan, R. J. *Chem. Rev.* **1996**, *96*, 635.

(2) (a) Pauson, P. L. *Tetrahedron* **1985**, *41*, 5855. (b) Pauson, P. L. Aspects of a Modern Interdisciplinary Field. In *Organometallics in Organic Synthesis*; De Meijere, A., tom Dieck, H., Eds.; Springer: Berlin, 1988; p 233. (c) Schore, N. E. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Paquette, L. A., Eds.; Pergamon Press: Oxford, U.K., 1991; Vol. 5, p 1037. (d) Chung, Y. K. *Coord. Chem. Rev.* **1999**, *188*, 297.

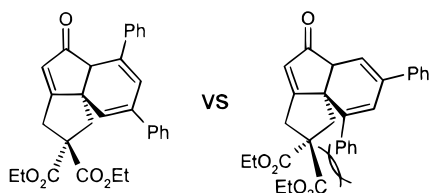
(3) (a) Ogliaruso, M. A.; Romanelli, M. G.; Becker, E. I. *Chem. Rev.* **1965**, *65*, 261. (b) Burk, M. J.; Calabrese, J. C.; Davidson, F.; Harlow, R. L.; Roe, D. C. *J. Am. Chem. Soc.* **1991**, *113*, 2209. (c) Brown, D. A.; Hargaden, J. P.; McMuulin, C. M.; Gogan, M.; Sloan, H. *J. Chem. Soc.* **1963**, 4914. (d) Östlich, S.; Broser, W.; Kurreck, H. *Z. Naturforsch., B.* **1977**, *32B*, 686. (e) Kapilov, J.; Evans, D. H. *J. Electroanal. Chem.* **1990**, *280*, 381. (f) Herndon, J. W.; Patel, P. P. *Tetrahedron Lett.* **1997**, *38*, 59. (g) Knölker, H.-J.; Heber, J.; Mahler, C. H. *Synlett* **1992**, 1002.

(4) (a) Hong, S. H.; Choi, D. S.; Chung, Y. K.; Lee, S. *Chem. Commun.* **1999**, 2099. (b) Rainier, J. D.; Imbriglio, J. E. *Organic Lett.* **1999**, *1*, 2037. (c) Son, S. U.; Paik, S.-J.; Lee, S. I.; Chung, Y. K. *J. Chem. Soc., Perkin Trans. 1* **2000**, 141.

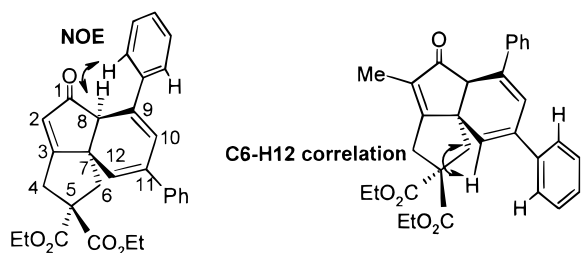
(5) (a) Lautens, M.; Klute, W.; Tam, W. *Chem. Rev.* **1996**, *96*, 49. (b) Yamamoto, Y.; Kitahara, H.; Ogawa, R.; Itoh, K. *J. Org. Chem.* **1998**, *63*, 9610. (c) Yamamoto, Y.; Nagata, A.; Itoh, K. *Tetrahedron Lett.* **1999**, *40*, 5035. (d) Yamamoto, Y.; Kitahara, H.; Hattori, R.; Itoh, K. *Organometallics* **1998**, *17*, 1910.



Compound **1A** was derived from the reaction of carbonylative [2 + 2 + 1] cycloaddition of diyne followed by [2 + 2 + 2] cycloaddition between the in situ generated bicyclic cyclopentadienone and two phenylacetylenes. Generally, intermolecular [2 + 2 + 2] cyclotrimerizations of alkynes encounter many difficulties.<sup>7</sup> Chemo- and regioselectivity problems lead to complex mixtures of products, which severely limit the utility of this reaction. However, in eq 1 other isomers were not found presumably due to steric congestion.



The structure of **1A** was established by various <sup>1</sup>H and <sup>13</sup>C NMR spectroscopic investigations (COSY, long-range COSY, DEPT, HETCOR, long-range HETCOR, phase-sensitive NOESY, and 2D-INADEQUATE). The decisive pieces of evidence for the structure of **1A** (and **5A**) were the observance of the NOE between H(8) and *ortho* hydrogens on the phenyl group at C(9) and a correlation peak between C(6) and H(12) in the C–H correlation spectrum.



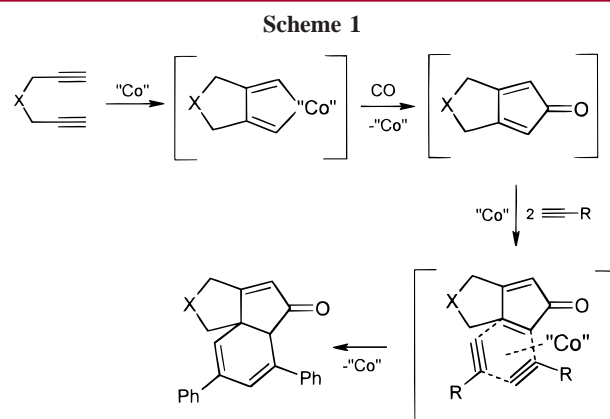
Thus, the cycloaddition reaction was quite regioselective and can provide a very useful synthetic procedure (Table 1). The tandem [2 + 2 + 1]/[2 + 2 + 2] cycloaddition of

(6) To a stainless steel reactor were added **1** (0.26 g, 1.10 mmol), Co<sub>2</sub>(CO)<sub>8</sub> (18.8 mg, 5.0 mol %), phenylacetylene (0.266 mL, 2.42 mmol), and 15 mL of CH<sub>2</sub>Cl<sub>2</sub>. The solution was bubbled with CO for 5 min, subjected to 30 atm of CO, and heated at 130 °C for 18 h. After the reactor was cooled to room temperature, the excess gas was released and the solution was filtered, concentrated, and chromatographed on a silica gel column eluting with hexane and diethyl ether (v/v, 5:1). After the solvent was removed **1A** was obtained in 68% yield (based on the diyne used).

$\alpha,\omega$ -heptadiynes **2–4** with two phenylacetylenes under CO pressure gave **2A–4A** in 76, 81, and 74% yields, respectively. Dienes having a quaternary center at the 4-position (**1–4**) gave the desired cycloaddition products (**1A–4A**) in good yields. When **5**, the monosubstituted diyne, having a quaternary center at the 4-position, was subjected to the catalyzed coupling with phenylacetylene, **5A** was obtained only in 9% yield with 67% of reactant recovered. Treatment of 1,6-heptadiyne **6** with two phenylacetylenes under CO pressure gave a 3:2 mixture of **6A** and **6B** in 57% yield. Compound **6B** was the major product when the reaction was carried out in the absence of phenylacetylene.<sup>4a</sup> For the disubstituted diyne **7**, a [2 + 2 + 2] cycloaddition product<sup>9</sup> **7C** was obtained in 30% yield with 62% of reactant recovered. For the oxygen-containing substrate **8**, the oxatricyclic enone derivative **8A** was obtained in 18% yield with a concomitant formation of **8B** in 29% yield. The regiochemistry of **8A** was the same as that of **5A**. Reaction of nitrogen-containing substrate **9** gave a 1:2 mixture of **9A** and **9C** in 58% yield. Thus, for all the diynes having a quaternary center at the 4-position, **A** is formed as a sole product and for other diynes other cycloaddition reactions (formation of **B** or **C**) become predominant. It seems that the steric effect of a substituent at the external terminus of the diyne substrate is an important factor for the tandem cycloaddition to proceed.

We have screened other alkynes such as trimethylsilylacetylene, octa-1-yne, benzylacetylene, and 1-thienylacetylene as an alkyne substrate. Treatment of **2** with 1-thienylacetylene under the same reaction conditions afforded **10A** and **10B** in 8 and 23% yield, respectively. However, for other alkynes, only tetracyclic products **B** were obtained.

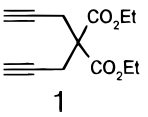
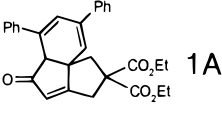
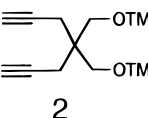
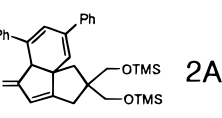
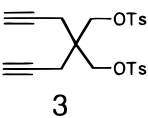
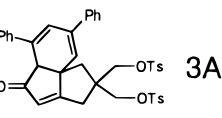
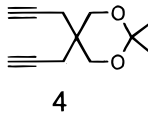
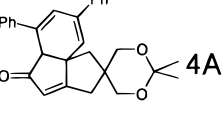
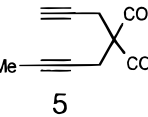
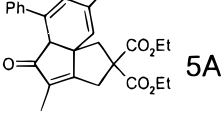
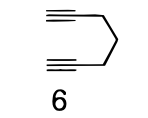
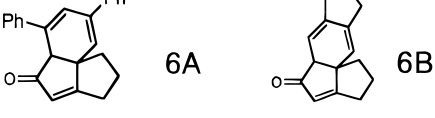
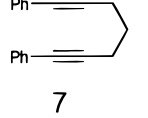
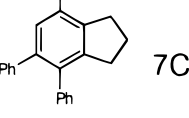
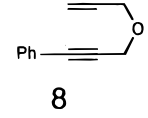
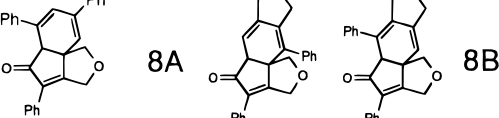
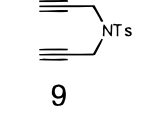
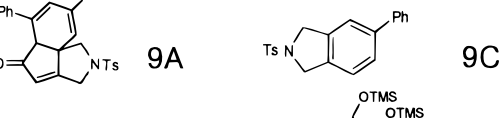
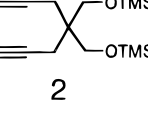
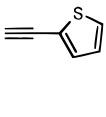
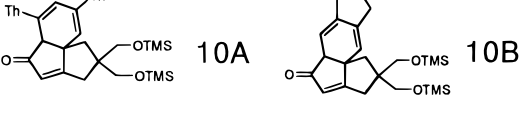
Following the generally accepted mechanism of metal-catalyzed cyclotrimerization, a plausible mechanism for the tandem [2 + 2 + 1]/[2 + 2 + 2] cycloaddition is proposed in Scheme 1.



As illustrated, the reaction proceeds through a Pauson–Khand-type carbonylative cycloaddition between diyne and

(7) Grotjahn, D. B. In *Comprehensive Organometallic Chemistry II*; Hegedus, L. S., Ed.; Pergamon: Oxford, 1995; Vol. 12, Chapter 7.3.

**Table 1.**  $\text{Co}_2(\text{CO})_8$ -Catalyzed Tandem [2 + 2 + 1] and [2 + 2 + 2] Cycloaddition<sup>a</sup>

entry	diyne	alkyne	product	yield(%) <sup>b</sup>
1		$\equiv\text{Ph}$		68
2		$\equiv\text{Ph}$		76
3		$\equiv\text{Ph}$		81
4		$\equiv\text{Ph}$		74
5		$\equiv\text{Ph}$		9 <sup>c</sup>
6		$\equiv\text{Ph}$		33/24
7		$\equiv\text{Ph}$		30 <sup>d</sup>
8		$\equiv\text{Ph}$		18/29
9		$\equiv\text{Ph}$		19/39
10				8/23

<sup>a</sup> Reaction conditions: 130 °C,  $\text{CH}_2\text{Cl}_2$ , 18 h, 5 mol %  $\text{Co}_2(\text{CO})_8$ , and 30 atm CO pressure. <sup>b</sup> Isolated yield. <sup>c</sup> Reactant was recovered in 67%. <sup>d</sup> Reactant was recovered in 62%.

carbon monoxide to form bicyclic cyclopentadienone. Subsequent [2 + 2 + 2] cycloaddition of bicyclic cyclopentadienone with two phenylacetylenes followed by reductive elimination leads to the product.

In conclusion, we have demonstrated that by the judicious choice of diyne substrate and an alkyne a tandem [2 + 2 + 1] and [2 + 2 + 2] cycloaddition reaction yields tricyclic compounds. In contrast to other trimerization of alkynes, the

reaction is highly regioselective to give 5-5-6 tricyclic compounds. Further application of this method and the mechanistic elucidation are now underway.

**Acknowledgment.** This work was supported by the Korea Science and Engineering Foundation (KOSEF) (1999-1-122-

---

(8) (a) Schore, N. E. In *Comprehensive Organic Synthesis: Selectivity, Strategy, and Efficiency in Modern Organic Chemistry*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: New York, 1991; Vol. 5, Chapter 9.4, pp 1129–1162. (b) McDonald, F. E.; Zhu, H. Y. H.; Holmquist, C. R. *J. Am. Chem. Soc.* **1995**, *117*, 6605.

001-5), the Ministry of Education (1998-015-D00165), and the KOSEF through Center for Molecular Catalysis. S.U.S. thanks Brain Korea 21 for the fellowship.

**Supporting Information Available:** Experimental procedures and spectral data for all new compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

OL000108J