Rhodium-catalyzed isomerization of unactivated alkynes to 1,3-dienes†

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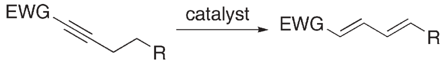
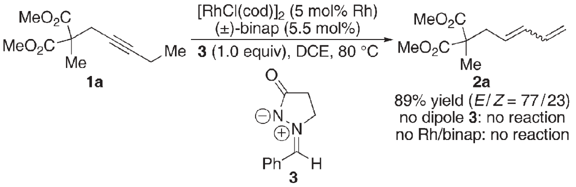
A rhodium/binap complex has been found to effectively catalyze the isomerization of unactivated internal alkynes to the corresponding 1,3-dienes in the presence of an azomethine imine as the reaction promoter.

Isomerization of organic compounds catalyzed by transition-metal complexes can provide a mild and efficient process that may not be easily achieved under conventional thermal conditions.[1] For isomerization of internal alkynes to 1,3-dienes, several transition-metal complexes (*e.g.*, Ru, Ir, and Pd complexes) are known to catalyze such a reaction when the alkyne is directly attached to an electron-withdrawing group (eqn. 1).[2] On the other hand, very little progress has been described for the isomerization of unactivated alkynes to the corresponding 1,3-dienes. In fact, to the best of our knowledge, only one recent report by Mitsudo has addressed this issue to date: a ruthenium complex can catalyze the isomerization of several simple internal alkynes with moderate efficiency.[3,4] In this Communication, we report that a rhodium complex can effectively catalyze the isomerization of unactivated internal alkynes to 1,3-dienes in high yield.[5]



(1)

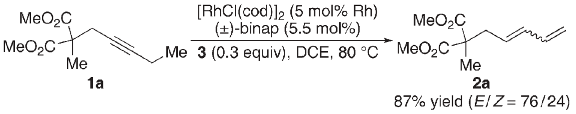
Initially, we conducted a reaction of alkyne **1a** in the presence of dipole **3**[6,7] by the use of 5 mol% Rh/binap catalyst in 1,2-dichloroethane at 80 °C, and found that **1a** was cleanly isomerized to 1,3-diene **2a** in 89% isolated yield (eqn. 2). In comparison, no reaction occurred in the absence of dipole **3** or the Rh/binap catalyst, indicating both components are necessary to promote this isomerization reaction.



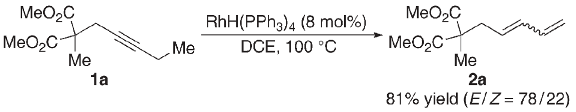
(2)

Under these conditions, the scope of this isomerization reaction is illustrated in Table 1.‡ Thus, substrates with a bulky primary alkyl group and ethyl group on the alkyne selectively provide terminal 1,3-dienes in 76–84% yield (entries 1–3). Alkynes with a secondary alkyl group and ethyl group are also isomerized to terminal 1,3-dienes selectively (entry 4). Alkynes bearing a longer alkyl substituent can also be employed to furnish internal 1,3-diene products, although their efficient isomerization requires a higher reaction temperature (100 °C; entries 5–8). In addition, it is worth noting that various functional groups, such as ethers, esters, alkenes, ketones, and carbamates, are compatible with this process.

We then carried out some experiments to probe the catalytically active species in the present reaction system. Thus, alkyne **1a** is fully converted to **2a** by the use of only 0.3 equiv of dipole **3** (eqn. 3), indicating that dipole **3** may react with a Rh/binap complex, rather than with substrate **1a**, to generate an active rhodium catalyst. Because transition-metal hydride complexes are typically used as catalysts for the isomerization of electron-deficient alkynes,[2] the active catalyst in this process could also be a rhodium hydride species. Unfortunately, however, direct observation of such a species by treatment of $[RhCl(cod)]_2$/(±)-binap with dipole **3** has not been successful so far. To examine the feasibility of a rhodium hydride catalyst, we employed a readily available rhodium hydride complex, $RhH(PPh_3)_4$, as the catalyst (eqn. 4). Although the catalyst activity of this complex is somewhat lower, alkyne **1a** is cleanly isomerized to 1,3-diene **2a** in 81% yield.

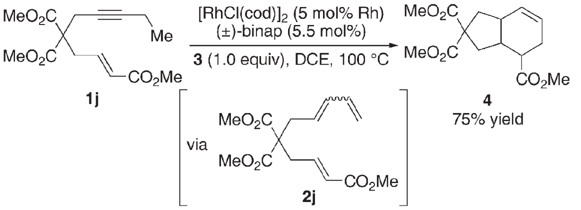


(3)



(4)

The use of an alkyne tethered to an electron-deficient olefin led to a tandem isomerization/Diels–Alder reaction, furnishing bicyclic compound **4** in 75% yield along with 3% yield of uncyclized diene **2j** (eqn. 5).[3]



(5)

In summary, we have developed a rhodium-catalyzed isomerization of unactivated alkynes to 1,3-dienes by using dipole **3** as the reaction promoter. Although the exact role of this dipole is unclear at this moment, the generation of a rhodium hydride may be the key to this catalyst system. Future studies will focus on the investigation of the reaction mechanism as well as further utilization of this interesting effect of 1,3-dipoles.

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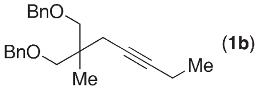
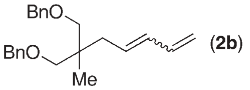
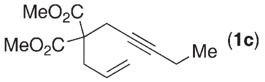
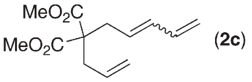
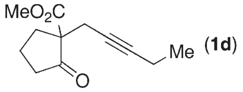
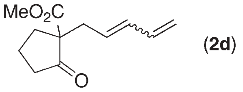
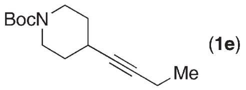
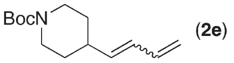
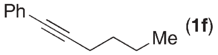
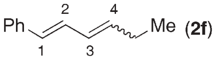
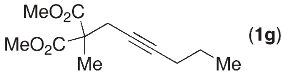
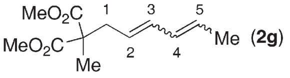
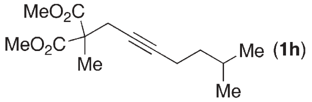
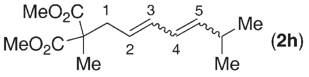
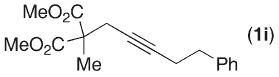
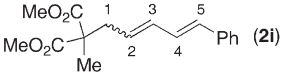
Table 1 Rhodium-catalyzed isomerization of alkynes to 1,3-dienes[a]

Entry	Substrate	Product	Yield (%)	(*E*/*Z*)
1[b]	 (**1b**)	 (**2b**)	76	(73/27)
2	 (**1c**)	 (**2c**)	84	(69/31)
3	 (**1d**)	 (**2d**)	76	(83/17)
4	 (**1e**)	 (**2e**)	81[c]	(85/15)
5[d]	 (**1f**)	 (**2f**)	73	(71/29)[e]
6[d]	 (**1g**)	 (**2g**)	84	(49/35/8/8)[f]
7[d]	 (**1h**)	 (**2h**)	87	(84/9/7)[g]
8[d]	 (**1i**)	 (**2i**)	83	(81/19)[h]

[a] Conditions: $[RhCl(cod)]_2$ (5 mol% Rh), (±)-binap (5.5 mol%), dipole **3** (1.0 equiv), 1,2-dichloroethane, 80 °C. [b] The reaction was conducted in the presence of 7 mol% rhodium catalyst. [c] Contaminated with an unidentified byproduct (~5%). [d] The reaction was conducted at 100 °C. [e] The ratio of (1*E*,3*E*)/(1*E*,3*Z*). [f] The ratio of (2*E*,4*E*)/(2*E*,4*Z*)/(2*Z*,4*E*)/(2*Z*,4*Z*). [g] The ratio of (2*E*,4*E*)/(2*E*,4*Z*)/(2*Z*,4*E*). [h] The ratio of (2*E*,4*E*)/(2*Z*,4*E*).

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Notes and references

‡ General procedure for the isomerization reaction: A solution of $[RhCl(cod)]_2$ (2.5 mg, 10 μmol Rh) and (±)-binap (6.8 mg, 11 μmol) in 1,2-dichloroethane (0.3 mL) was stirred for 5 min at room temperature. Dipole **3** (34.8 mg, 0.20 mmol) and alkyne **1** (0.20 mmol) were added to it with additional 1,2-dichloroethane (0.3 mL), and the mixture was stirred for 24–72 h at 80–100 °C. After being cooled to room temperature, the reaction mixture was directly passed through a pad of silica gel with EtOAc, and the solvent was removed under vacuum. The residue was purified by silica gel preparative TLC with Et_2O/hexane to afford 1,3-diene **2**.

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