Palladium-Catalyzed Cyclizations of 1,6-Dienes in the Presence of Lewis Acids

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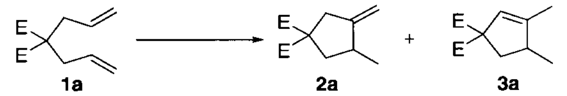
Palladium-catalyzed cyclizations of several 1,6-dienes were accomplished by utilizing a catalytic amount of additives. Use of Lewis acids gave the endocyclic compounds, while use of silver(I) salts gave the exocyclic compounds.

Although some palladium complexes could catalyze cyclizations of enynes with excellent regio- and stereoselectivity, palladium-catalyzed cyclizations of 1,6-dienes are slower and require harsher reaction conditions, mainly due to lower reactivities of 1,6-dienes toward transition metal complexes compared to diynes or enynes.[1] Recently, RajanBabu showed excellent conversion of the dienes to the corresponding exomethylenecyclopentanes by using allylnickel bromide dimer with silver triflate.[2] Itoh reported an efficient ruthenium(II) catalyzed cycloisomerization of 1,6-dienes to the exomethylenecyclopentanes up to 95% isolated yields.[3] Note that the products obtained from these reactions are similar to those from palladium-catalyzed cycloreductions of enynes. In continuing our program in developing an efficient method leading to exomethylenecyclopentanes, we have carried out a study on cycloisomerization of 1,6-dienes under palladium catalysis. We focused on cationic palladium complexes that are known to favor dimerization of alkenes.[4] Heumann showed that cationic palladium complexes generated from palladium compounds plus silver(I) salts catalyzed transformation of the dienes to the exomethylenecyclopentanes along with their isomers.[5] More, recently, Widenhoefer reported that chiral cationic palladium compounds were highly effective for asymmetric sequential cyclization/silylation of 1,6-dienes and cationic palladium phenanthroline complexes catalyzed the cycloisomerization of 1,5- and 1,6-dienes to form cyclopentenes.[6] Yet further developments for regio- and stereoselective cycloisomerization of 1,6-dienes to the exomethylenecyclopentanes are expected. Herein we wish to report our recent results on regioselective cyclizations of 1,6-dienes to the exomethylenecyclopentanes by employing palladium catalysts and Lewis acids as additives.

Diethyl diallylmalonate was tested first. Allylpalladium chloride dimer did not catalyze diene cyclization as known. Combination of allylpalladium chloride dimer with cocatalysts catalyzed cyclizations of diethyl diallylmalonate as shown in Table 1. Silver tetrafluoroborate, boron trifluoride etherate, zinc chloride, chromium chloride, or nickel chloride seemed to increase catalytic activity for this cyclization. With regard to roles of the additives, it is important to note that use of boron trifluoride etherate, zinc chloride, chromium chloride, or nickel chloride gave rise to the endocyclic compound **3a** with high regioselectivity. In contrast, use of silver(I) salts regioselectively gave the exomethylenecyclopentane **2a**.

Then, our attention was paid to a diene-coordinated palladium compound, (COD)PdMeCl,[7] which might undergo facile ligand exchange with another diene. Surprisingly, a mixture of (COD)PdMeCl and AgOTf catalyzed cyclization of the diene **1a** to the exomethylenecyclopentane **2a** in excellent yield along with a small amount of its isomer **3a** when the reaction solution was quenched with an equivalent amount of triethylamine (entry 6). It is worth noting that addition of the substrate to triethylamine-containing catalytic system did not induce any reaction even for a day in refluxing chloroform.

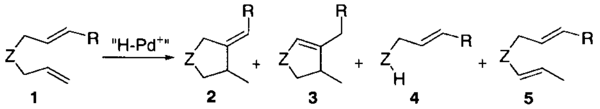
Table 1. Pd-Catalyzed cycloisomerizations of diethyl diallylmalonate in the presence of additives



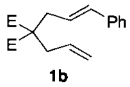
	Catalysts (5 mol% / 5 mol%)	Solvent	Temp(°C) /Time(h)	Yield(%) (**2a** : **3a**)
1	(π-allyl PdCl)$_2$/BF$_3$OEt$_2$	CHCl$_3$	50/2	78 (10:90)
2	(π-allyl PdCl)$_2$/ZnCl$_2$	CHCl$_3$	50/2	88 (4:96)
3	(π-allyl PdCl)$_2$/CrCl$_2$	Toluene	80/14	80 (**3a** only)
4	(π-allyl PdCl)$_2$/NiCl$_2$	Toluene	85/10	88 (**3a** only)
5	(π-allyl PdCl)$_2$/AgBF$_4$	Toluene	50/2	78(30:70)
6	(COD)PdMeCl/AgOTf	CHCl$_3$	rt/2	98 (95:5)

In order to explore scope and limitations of the present cyclization method, we have attempted cyclization of several other dienes under the similar conditions as shown in Table 2. The catalyst system, a 1:1 mixture of (COD)PdMeCl and silver triflate, successfully catalyzed the dienes **1a–d** to give the

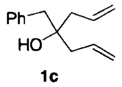
Table 2. Pd-Catalyzed cycloisomerization of dienes in the presence of 5 mol% silver(I) salts



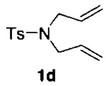
Substrates	Additives	Temp(°C) /Time(h)	Yield(%)	
			2, 3	**4, 5**
1a	AgBF$_4$	rt/2	75, 20	
	AgOTf	rt/2	93, 4	
1b	AgBF$_4$	rt/2	92, 0	
	AgOTf	40/8	63, 0	
1c	AgOTf	rt/15	77, 0	
1d	AgOTf	rt/20	60, 0	23 (**4d**)
1e	AgOTf	rt/6		60 (**4e**)
1f	AgOTf	rt/8		75 (**5f**)



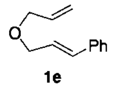
1b



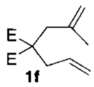
1c



1d



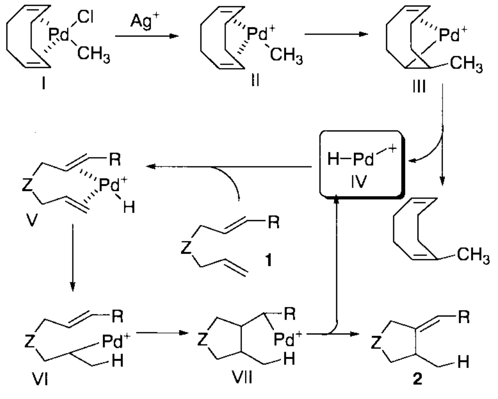
1e



1f

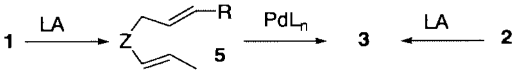
desired products **2a–d** in 60–93% yields. However, allyl cinnamyl ether **1e** underwent the cleavage of the ether functionality to give cinnamyl alcohol, presumably formed from hydrolysis of the intermediate **5e**. The diene **1f** under these conditions did produce only the rearranged diene **5f**.

A mechanistic proposal might be inferred from these examples as shown in Scheme 1. (COD)Pd(Me)Cl (I) is expected to react rapidly with silver(I) salts to form [L–Pd–H]$^+$ species (IV). The species (IV) then might hydropalladate at the sterically less hindered olefin to give the alkylpalladium intermediate (VI) which could undergo carbopalladation and subsequent β-elimination to form the desired products **2**.



Scheme 1.

In contrast, Lewis acid might catalyze isomerization of 1,6-dienes **1** to 1,5-dienes **5** prior to Pd-catalyzed cyclization or isomerization of the products **2** to the more stable products **3** as shown in eq 1. Since we isolated the rearranged diene **5f** from **1f** and the cleavage products **4d** and **4e** from **1d** and **1e**, the reaction might proceed more likely via double bond isomerization followed by cyclization.



In summary, palladium-catalyzed cyclizations of 1,6-dienes were accomplished by utilizing a catalytic amount of palladium compounds and various additives. Lewis acids as additives might increase the reactivity of one of double bond, while silver(I) salt might activate palladium catalyst to the cationic palladium species.

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References and Notes

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