

Cationic Rhodium(I)–dppf Complex-Catalyzed Olefin Isomerization/Propargyl Claisen Rearrangement/Carbonyl Migration Cascade

Ken Tanaka,* Eri Okazaki, and Yu Shibata

Department of Applied Chemistry, Graduate School of Engineering, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan

Received May 12, 2009; E-mail: tanaka-k@cc.tuat.ac.jp

Cascade reactions, which can eliminate a number of reaction steps and reduce hazardous waste, have attracted much attention in current organic synthesis.¹ It is well-known that transition-metal complexes are able to activate σ bonds by oxidative addition of those bonds to the transition metal or by an electrophilic substitution pathway;² π bonds can also be activated through the formation of a complex between an electrophilic transition metal and the π electrons of alkene or alkyne multiple bonds.³ Sequential activation of these bonds by a single transition-metal complex would allow the development of a novel cascade reaction. For such a process, a cationic rhodium(I) complex is a promising catalyst, as these complexes can catalyze isomerizations⁴ of alkenes or alkynes via a π -allyl intermediate generated through cleavage of an allylic C–H bond,⁵ hydroacylations of alkenes or alkynes via aldehyde C–H bond activation,⁶ and aromatic amino-Claisen rearrangements via π -bond activation.⁷

As a target for a cationic Rh(I) complex-catalyzed cascade reaction, we focused on a combination of olefin isomerization and the propargyl Claisen rearrangement that has not been realized to date.⁸ Toste and Sherry previously reported the novel cationic gold(I)-catalyzed Claisen rearrangement of propargyl vinyl ethers to allenic aldehydes.^{9,10} If an isomerization of readily prepared and stable allyl propargyl ethers to propargyl vinyl ethers followed by the propargyl Claisen rearrangement can be catalyzed by a single cationic Rh(I) complex, this would be useful from a synthetic point of view. Furthermore, the product allenic aldehyde might react with the cationic Rh(I) complex to form another product.¹¹ Here we describe cationic Rh(I)–dppf complex-catalyzed isomerizations of allyl propargyl ethers to allenic aldehydes and dienals (Scheme 1).

We first investigated the reaction of allyl propargyl ether **1a** in the presence of a cationic Rh(I)–BINAP complex (5 mol %). Pleasingly, the expected olefin isomerization/Claisen rearrangement proceeded at room temperature to give the corresponding allenic aldehyde **2a**, and the carbonyl migration product, dienal **3a**, was also formed (Table 1, entry 1). Thus, various cationic Rh(I)–bisphosphine complexes were screened in order to realize the selective formation of **2a**. Among the ligands examined (entries 1–7), the use of dppf gave **2a** in the highest yield (entry 7). The selective formation of **3a** could also be realized by increasing the reaction temperature (80 °C) in the presence of the same Rh(I) catalyst (entry 8).

Thus, we explored the scope of the olefin isomerization/Claisen rearrangement cascade by using 5 mol % cationic Rh(I)–dppf complex (Table 2). The products were isolated as the corresponding reduced alcohols because of the instability of allenic aldehydes. Electronically

Scheme 1

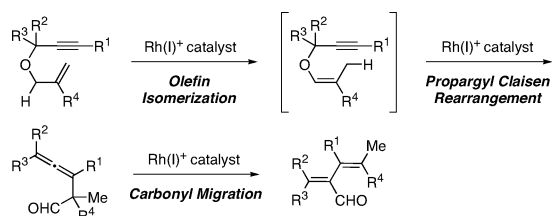


Table 1. Screening of Reaction Conditions for Rhodium-Catalyzed Isomerization of Allyl Propargyl Ether **1a**

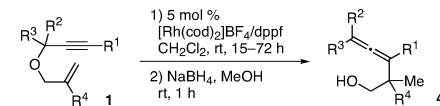
entry	ligand	temp (°C)	conv. (%) ^a	yield (%) ^a	
				2a	3a
1	BINAP	rt	100	39	27
2	H ₈ -BINAP	rt	100	67	0
3	Segphos	rt	100	70	0
4	BIPHEP	rt	100	67	0
5	dppb	rt	72	56	0
6	dppe	rt	10	0	0
7	dppf	rt	100	80	5
8	dppf	80	100	0	82

^a Determined by ¹H NMR.

diverse aryl and sterically diverse alkyl groups could be incorporated at the alkyne terminus (entries 1–5). With respect to substituents at the propargylic position, not only methyl- but also cycloalkyl- and isopropyl-substituted tertiary propargyl ethers could participate in this reaction, affording the corresponding tetrasubstituted allenenes in good yields (entries 1–7). Furthermore, tri- and disubstituted allenenes could also be obtained in good yields (entries 9 and 10). It is noteworthy that the reactions of both tertiary and secondary propargyl ethers proceeded under mild conditions (room temperature to 40 °C) in comparison with the precedent gold catalysis, which requires elevated temperatures (75 °C) for tertiary propargyl vinyl ethers.⁹ Phenyl instead of methyl substitution of the alkene moiety was tolerated, although a prolonged reaction time was required (entry 8).

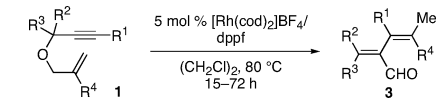
The scope of the olefin isomerization/Claisen rearrangement/carbonyl migration cascade was also examined using the same substrates and rhodium catalyst (Table 3). Interestingly, the isomerizations of tertiary propargyl ethers **1a–h** proceeded at 80 °C to yield the corresponding dienals in good yields (entries 1–8), but the isomerizations were terminated at the stage of the corresponding allenic aldehydes in the case of secondary and primary propargyl ethers **1i** and **1j** (entries 9 and 10).

A possible mechanism for the present isomerization is outlined in Scheme 2. In the first step, the olefin isomerization of allyl ether **1** proceeds to give enol ether **5**.¹² Next, the propargyl Claisen rearrangement proceeds through activation of the alkyne triple bond of **5**,¹³ affording allenic aldehyde **2**. At elevated temperature, activation of the aldehyde C–H bond followed by hydride elimination of the pendant allene furnishes rhodacycle **A**. Carbonyl migration then occurs, producing conjugated rhodacycle **B**.¹⁴ β -Hydride elimination followed by reductive elimination generates dienal **3**. When R³ = H, allenic aldehyde **2** rather than dienal **3** is generated,

Table 2. Cationic Rh(I)–dppf Complex-Catalyzed Isomerizations of Allyl Propargyl Ethers **1** to Homoallenic Alcohols **4**


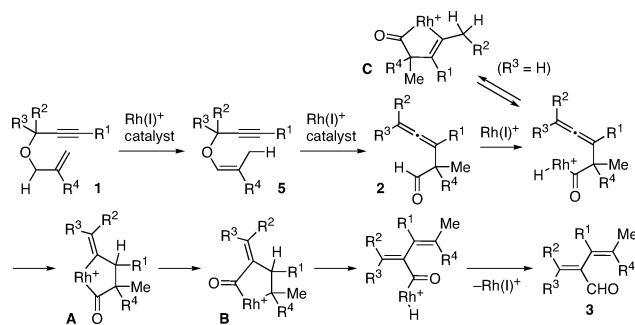
entry	1	R ¹	R ² , R ³	R ⁴	time (h)	4	yield (%) ^a
1	1a	Ph	Me, Me	Me	23	4a	74
2	1b	4-MeOC ₆ H ₄	Me, Me	Me	19	4b	72
3	1c	4-ClC ₆ H ₄	Me, Me	Me	44	4c	71
4	1d	<i>n</i> -Bu	Me, Me	Me	17	4d	69
5 ^b	1e	Cy	Me, Me	Me	30	4e	49
6	1f	Ph	(CH ₂) ₅	Me	23	4f	70
7	1g	Ph	<i>i</i> -Pr, Me	Me	15	4g	81
8 ^b	1h	Ph	Me, Me	Ph	72	4h	45
9	1i	Ph	Me, H	Me	17	4i	72
10	1j	Ph	H, H	Me	72	2j ^c	65

^a Isolated yield. ^b At 40 °C. ^c Isolated as allenic aldehyde **2j** without treatment with NaBH₄.

Table 3. Cationic Rh(I)–dppf Complex-Catalyzed Isomerizations of Allyl Propargyl Ethers **1** to Dienals **3**


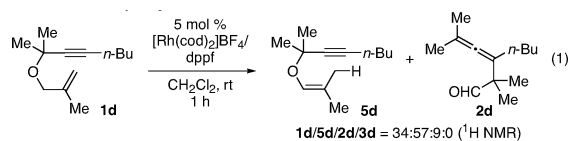
entry	1	R ¹	R ² , R ³	R ⁴	time (h)	3	% yield (E/Z) ^a
1	1a	Ph	Me, Me	Me	16	3a	82
2	1b	4-MeOC ₆ H ₄	Me, Me	Me	16	3b	76
3	1c	4-ClC ₆ H ₄	Me, Me	Me	16	3c	76
4	1d	<i>n</i> -Bu	Me, Me	Me	16	3d	72
5	1e	Cy	Me, Me	Me	72	3e	43 ^b
6	1f	Ph	(CH ₂) ₅	Me	16	3f	77
7	1g	Ph	<i>i</i> -Pr, Me	Me	16	3g	67 (4:1)
8	1h	Ph	Me, Me	Ph	40	3h	80 (2:1)
9	1i	Ph	Me, H	Me	15	3i	0 ^c
10	1j	Ph	H, H	Me	16	3j	0 ^d

^a Isolated yield. ^b The corresponding allenic aldehyde **2e** remained in ~32% yield. ^c Allenic aldehyde **2i** was generated in 61% yield. ^d Allenic aldehyde **2j** was generated in 35% yield along with the decarbonylated byproduct.

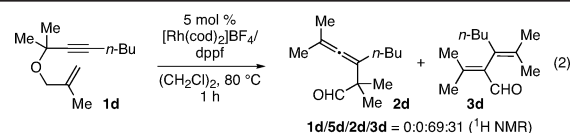
Scheme 2

presumably because of reversible hydride elimination through rhodacycle **C**.

Consistent with this pathway, enol ether **5d** and allenic aldehyde **2d** were initially observed by ¹H NMR spectroscopy at room temperature (eq 1) and 80 °C (eq 2), respectively.¹⁵



In conclusion, we have developed the cationic Rh(I)–dppf complex-catalyzed isomerizations of allyl propargyl ethers to allenic aldehydes and



dienals. Future work will focus on using the cationic Rh(I) complex for sequential activation of σ and π bonds in cascade reactions.

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Supporting Information Available: Experimental procedures and compound characterization data. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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- (12) No reaction was observed upon treatment of **1a** with 5 mol % PdCl₂ (CH₂Cl₂, rt, 16 h), which is known to be a very effective catalyst for isomerizations of allyl ethers to enol ethers through electrophilic double bond activation. Therefore, electrophilic double bond activation by the cationic Rh(I) complex might not be involved in this olefin isomerization, although the precise mechanism cannot be determined at the present stage. For a PdCl₂-catalyzed isomerization of allyl ethers, see: Mereyala, H. B.; Lingannagaru, S. R. *Tetrahedron* **1997**, *53*, 17501.
- (13) No reaction was observed upon treatment of isolated enol ether **5d** in refluxing CH₂Cl₂ for 14 h. Furthermore, the reaction of **1h** with 5 mol % Rh(I)–(S)-H₈-BINAP in refluxing CH₂Cl₂ furnished **4h** with 15% ee. These results clearly indicate that the cationic Rh(I) complex indeed catalyzes the propargyl Claisen rearrangement.
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- (15) Isolated crude **2a** (ca. >90% purity) was indeed transformed into **3a** in 72% isolated yield under the same conditions as entry 1, Table 3 [5 mol % Rh(I)–dppf, 80 °C, 16 h].

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