



## Rhenium-catalyzed reaction of carbonyl compounds with ketene silyl acetals

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### ARTICLE INFO

#### Article history:

Received 25 September 2009

Revised 20 November 2009

Accepted 26 November 2009

Available online 11 December 2009

### ABSTRACT

It was found that rhenium complex is an effective catalyst for the reaction of carbonyl compounds with ketene silyl acetals. A wide range of  $\beta$ -silyloxy esters is obtained by the treatment of carbonyl compounds with ketene silyl acetals in the presence of a catalytic amount of  $\text{ReBr}(\text{CO})_5$  in moderate to good yields.

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The reaction of carbonyl compounds with silicon nucleophiles, such as enol silyl ethers, allyl silanes, and ketene silyl acetals, is one of the useful methods for constructing carbon–carbon bond in organic synthesis.<sup>1</sup> There are many reports on these reactions. These reactions are usually attained with the aid of a Lewis acid promoter or catalyst. Therefore, several of these methods suffer from drawbacks such as strictly anhydrous and strongly acidic conditions.

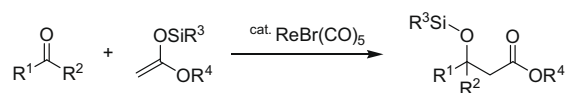
Recently, we have shown the hitherto unknown capacity of  $\text{ReBr}(\text{CO})_5$ , which is an air-stable and a water-tolerant compound, as an efficient catalyst for the reaction of carbonyl compounds with silicon and tin nucleophiles.<sup>2,3</sup> We now find that the coupling of carbonyl compounds with ketene silyl acetals occurred smoothly using the rhenium-complex catalyst under nearly neutral conditions to produce the corresponding  $\beta$ -silyloxy esters in moderate to good yields (Scheme 1).<sup>4,5</sup>

To investigate the optimized reaction conditions, benzaldehyde (**1a**) was reacted with ketene silyl acetals **2a–c** in the presence of a catalytic amount of  $\text{ReBr}(\text{CO})_5$  under various reaction conditions and these results are shown in Table 1. When 1-(*tert*-butoxy)-1-(trimethylsilyloxy)ethene (**2a**) was allowed to react with **1a** in the presence of the  $\text{ReBr}(\text{CO})_5$  catalyst in benzene solvent at 80 °C for 1 h, the coupling products were obtained in 71% yield as a mixture of the  $\beta$ -hydroxy ester **3** and carboxylic acid **4** (entry 3). At lower reaction temperatures, the yields of the coupling products decreased (entries 1–2). Even when toluene, dichloroethane, and THF instead of benzene were used as solvents, the coupling of **1a** with **2a** proceeded smoothly to give the corresponding coupling products in good yields, whereas the use of coordinating solvent such as acetonitrile significantly decreased the yield of the products (entries 4–7). The yields and selectivity of the coupling products,  $\beta$ -hydroxy ester **3**,  $\beta$ -hydroxy carboxylic acid **4**, and  $\beta$ -silyloxy ester **5**, were affected by the ketene silyl acetal used. When 1-(*tert*-butoxy)-1-(trimethylsilyloxy)ethene (**2a**) was used, the coupling products were obtained with a mixture of  $\beta$ -hydroxy ester **3a** (57%) and carboxylic acid **4a**

(14%) (entry 3). In the case of 1-(*tert*-butoxy)-1-(*tert*-butyldimethylsilyloxy)ethene (**2b**), having a bulky *tert*-butyldimethylsilyloxy and *tert*-butyl groups, some complicated by-products were formed and the coupling products were not confirmed (entry 8). For the reaction of 1-(*tert*-butyldimethylsilyloxy)-1-methoxyethene (**2c**), the coupling reaction proceeded to give the methyl 3-(*tert*-butyldimethylsilyloxy)-3-phenylpropanoate (**5c**) in 95% yield with a high selectivity (entry 9).<sup>6</sup>

In order to determine the applicability of the preparation of various  $\beta$ -silyloxy esters, various carbonyl compounds were reacted with **2c** in the presence of a catalytic amount of  $\text{ReBr}(\text{CO})_5$  at 80 °C for 1 h. These results are shown in Table 2. 4-Methyl-, 4-methoxy-, and 4-chlorobenzaldehyde were also coupled with **2c** to give the  $\beta$ -silyloxy ester **5** in 85–91% yields (entries 1–3). When 4-nitrobenzaldehyde substituted with an electron-withdrawing group was treated with **2c** under the same reaction conditions as that of benzaldehyde (**1a**), the yield of the coupling product decreased; however, the product yield was improved by extending the reaction time (entry 4). Similarly, aliphatic aldehydes, such as hexanal, isobutylaldehyde, and pivalaldehyde, were coupled with **2c** to give the coupling products in good yields by extending the reaction time (entries 5–7). Arylalkyl-, dialkyl-, and cyclic ketones as well as aldehydes gave the corresponding  $\beta$ -silyloxy esters **5** in good yields for longer reaction times (entries 8–10).

For the coupling reaction of benzaldehyde (**1a**) with (*E*)-1-(*tert*-butoxy)-1-(trimethylsilyloxy)propene (**2d**), the *anti*- $\beta$ -hydroxy ester was preferentially formed in 68% yield (*anti/syn* = 79/21) (Scheme 2). Similarly, **1a** was coupled with (*Z*)-1-(*tert*-butoxy)-1-(trimethylsilyloxy)propene (**2e**) with *anti* selectivity to give the coupling products as a mixture of the  $\beta$ -hydroxy ester (45%, *anti/syn* = 72/28) and carboxylic acid (22%, *anti/syn* = 67/33). 1-Methoxy-2-methyl-1-(trimethylsilyloxy)propene (**2f**) was also coupled



Scheme 1.

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**Table 1**  
Rhenium-catalyzed coupling reaction of benzaldehyde (**1a**) with ketene silyl acetals **2a–c**<sup>a</sup>

entry	R <sup>1</sup>	R <sup>2</sup>	temp (°C)	solvent	yield / % <sup>b</sup>		
					3	4	5
1	Me	<sup>t</sup> Bu ( <b>2a</b> )	25	benzene	trace	trace	trace
2	Me	<sup>t</sup> Bu ( <b>2a</b> )	60	benzene	22	6	trace
3	Me	<sup>t</sup> Bu ( <b>2a</b> )	80	benzene	57	14	trace
4	Me	<sup>t</sup> Bu ( <b>2a</b> )	80	toluene	35	15	trace
5	Me	<sup>t</sup> Bu ( <b>2a</b> )	80	ClCH <sub>2</sub> CH <sub>2</sub> Cl	48	8	trace
6	Me	<sup>t</sup> Bu ( <b>2a</b> )	80	THF	47	trace	trace
7	Me	<sup>t</sup> Bu ( <b>2a</b> )	80	CH <sub>3</sub> CN	trace	0	trace
8 <sup>c</sup>	<sup>t</sup> Bu	<sup>t</sup> Bu ( <b>2b</b> )	80	benzene	—	—	—
9 <sup>d</sup>	<sup>t</sup> Bu	Me ( <b>2c</b> )	80	benzene	0	0	95 (74)

<sup>a</sup> Reaction conditions: **1a** (0.3 mmol), **2** (0.4 mmol), ReBr(CO)<sub>5</sub> (0.025 mmol) and solvent (3 mL) for 1 h.

<sup>b</sup> <sup>1</sup>H-NMR yield based on **1a**. The number in parenthesis shows the isolated yield.

<sup>c</sup> Some complicated by-products were formed.

<sup>d</sup> After the reaction, desilylation with HCl aq. was not carried out.

with **1a** to give 3-hydroxy-2,2-dimethyl-3-phenylpropanoate in 74% yield (Scheme 3).

It has already been reported that the coordinative unsaturated 16-electron complex, ReBr(CO)<sub>4</sub>, was generated by the dissociation of carbon monoxide from ReBr(CO)<sub>5</sub> under toluene reflux conditions.<sup>7</sup> Based on this information, we suggested that the coordinative unsaturated rhenium species would act as a Lewis acid catalyst during the coupling reaction.

For the reaction of (*E*)- and (*Z*)-1-(*tert*-butoxy)-1-(trimethylsilyloxy)propenes, **2d** and **2e**, it was found that the *anti*-addition products were preferentially formed and the selectivity was not dependent on the geometry of the ketene silyl acetal. Although, at the present time, we cannot get a clear reason why the *anti*-iso-

**Table 2**  
Rhenium-catalyzed coupling reaction of carbonyl compounds with 1-(*tert*-butyldimethylsilyloxy)-1-methoxyethene (**2c**)<sup>a</sup>

entry	R <sup>1</sup>	R <sup>2</sup>	yield / % <sup>b</sup>
1	4-CH <sub>3</sub> C <sub>6</sub> H <sub>4</sub>	H	91 (80)
2	4-CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub>	H	85 (76)
3	4-ClC <sub>6</sub> H <sub>4</sub>	H	85 (70)
4 <sup>c</sup>	4-NO <sub>2</sub> C <sub>6</sub> H <sub>4</sub>	H	97 (81)
5	<sup>n</sup> C <sub>5</sub> H <sub>11</sub>	H	83 (73)
6 <sup>c</sup>	<sup>i</sup> C <sub>3</sub> H <sub>7</sub>	H	87 (66)
7 <sup>c</sup>	<sup>t</sup> C <sub>4</sub> H <sub>9</sub>	H	87 (67)
8 <sup>c</sup>	C <sub>6</sub> H <sub>5</sub>	CH <sub>3</sub>	75 (63)
9 <sup>d</sup>	C <sub>2</sub> H <sub>5</sub>	C <sub>2</sub> H <sub>5</sub>	72 (50) <sup>e</sup>
10 <sup>c</sup>	-(CH <sub>2</sub> ) <sub>5</sub> -		94 (67)

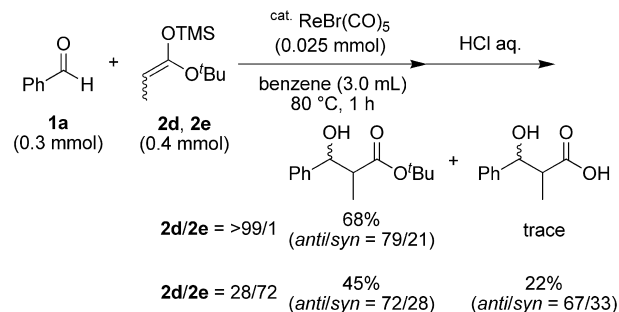
<sup>a</sup> Reaction conditions: **1** (0.3 mmol), **2c** (0.4 mmol), ReBr(CO)<sub>5</sub> (0.025 mmol) and benzene (3 mL) at 80 °C for 1 h.

<sup>b</sup> <sup>1</sup>H-NMR yield based on **1**. The numbers in parenthesis show the isolated yields.

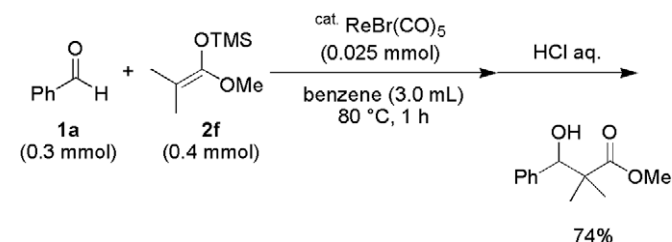
<sup>c</sup> For 6 h.

<sup>d</sup> For 15 h.

<sup>e</sup> A small amount of bis(*tert*-butyldimethylsilyl)ether (0.02 mmol) was also obtained as inseparable mixture.



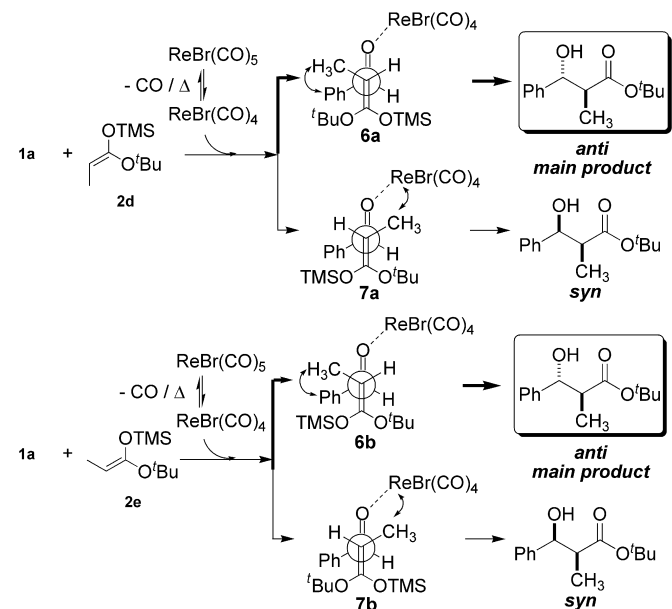
**Scheme 2.** Rhenium-catalyzed coupling reaction of benzaldehyde (**1a**) with (*E*)- and (*Z*)-1-(*tert*-butoxy)-1-(trimethylsilyloxy)propene.



**Scheme 3.** Rhenium-catalyzed coupling reaction of benzaldehyde (**1a**) with 1-methoxy-2-methyl-1-(trimethylsilyloxy)propene (**2f**).

mer was preferentially formed on these reactions, a plausible cause is as follows. The steric interactions on intermediates **7a** and **7b** are greater than those of intermediates **6a** and **6b** due to the steric repulsion of CH<sub>3</sub> and ReBr(CO)<sub>4</sub> coordinated with the carbonyl group (Scheme 4).<sup>8</sup> Therefore, it is suggested that the *anti*-products were preferentially formed.

In summary, we found that rhenium-catalyzed reaction of various carbonyl compounds such as not only aromatic and aliphatic aldehydes but also ketones with ketene silyl acetal **2c** gave the corresponding β-silyloxy esters in moderate to good yields.



**Scheme 4.** The formation of *anti*-isomer as a main product.

## Acknowledgments

This research was supported by a Grant-in-Aid for Science Research, and Strategic Project to Support the Formation of Research Bases at Private Universities from the Ministry of Education, Culture Sports, Science and Technology of Japan.

## Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2009.11.109.

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- Typical procedure*: A benzene (3.0 ml) solution of benzaldehyde (**1a**) (0.3 mmol), 1-(*tert*-butyldimethylsilyloxy)-1-methoxyethene (**2c**) (0.4 mmol) and ReBr(CO)<sub>5</sub> (0.025 mmol) was stirred under an atmosphere of nitrogen at 80 °C for 1 h. After the reaction was complete, H<sub>2</sub>O was added to the reaction mixture and extracted with diisopropylether. The organic layer was dried with MgSO<sub>4</sub>. The resulting mixture was filtered, and the filtrate was concentrated. Purification of the residue by silica gel column chromatography (hexane/EtOAc = 7/1) afforded the corresponding β-silyloxy ester in 74% yield. The structures of the products were assigned by their <sup>1</sup>H and <sup>13</sup>C-NMR, and mass spectra.
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