

# Communications

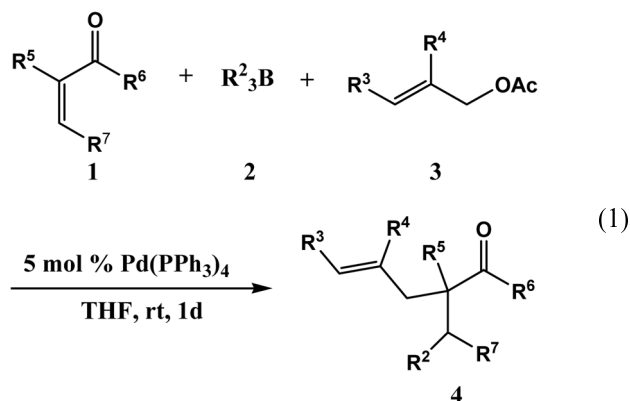
## Regiospecific Addition of Alkyl and Allyl Groups to $\alpha,\beta$ -Unsaturated Carbonyl Compounds with Trialkylboranes through the Palladium Catalyst

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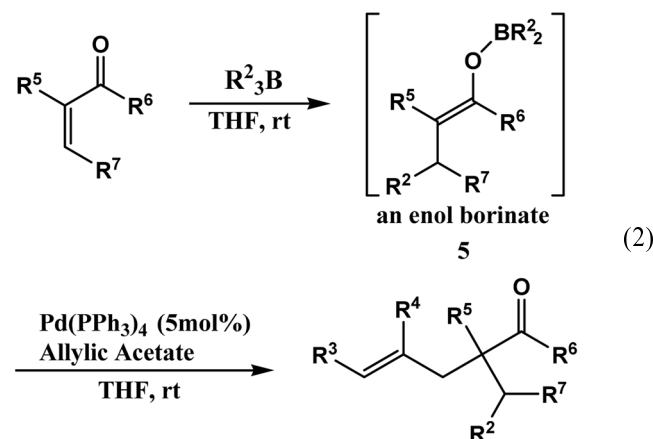
Trialkylboranes were well known to transfer an alkyl group to the  $\beta$ -position of  $\alpha,\beta$ -unsaturated aldehydes and ketones through radical chain mechanism.<sup>1a-d</sup> It is reported that trialkylborane reacted with acrolein,<sup>2a</sup>  $\alpha$ -methylacrolein,<sup>2b</sup>  $\alpha$ -bromolacrolein,<sup>2c</sup> methyl vinyl ketone,<sup>2c</sup> 2-methylcycloalkanones<sup>2d</sup> and isopropenyl methyl ketone<sup>2e</sup> to generate 1,4-addition products *via* hydrolysis of enol borinate intermediate with water. Mukaiyama reported for preparation of  $\beta$ -hydroxyketones by the reaction of vinyl-oxyboranes and carbonyl compounds.<sup>3</sup> Quite recently, Yamamoto reported  $\beta$ -alkyl- $\alpha$ -allylation of benzylidenemalononitrile using trialkylboranes and  $\pi$ -allylpalladium.<sup>4</sup> However such enol borinates were used only limited scope as a synthetic intermediates. In this paper, we wish to report that the generated enol borinate with  $\alpha,\beta$ -unsaturated carbonyl compounds can be used as good nucleophiles for the reaction with  $\pi$ -allylpalladium intermediates. The alkyl radical from **2** undergo 1,4-addition at the  $\beta$ -position of olefins and form an enol borinate. And generated enol borinate intermediate added to the  $\pi$ -allylpalladium of allyl compound and palladium. The reaction gave the  $\beta$ -alkyl and  $\alpha$ -allylated derivatives of the activated olefins in a direct process, with high to good yields (eq 1). The results are summarized in Table 1.




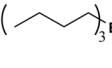
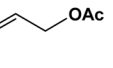
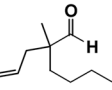
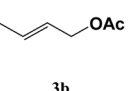
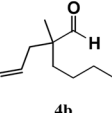
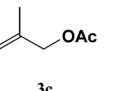
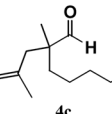
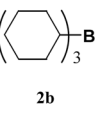
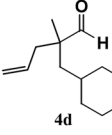
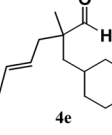
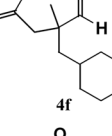

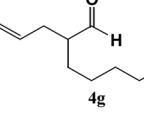
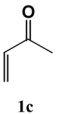
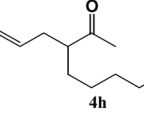
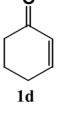
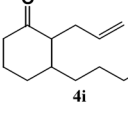
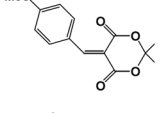

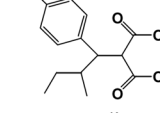
The reaction of methacrolein **1a** with tributylborane **2a** and allyl compounds (**3a**, **3b**, **3c**) at room temperature in the presence of Pd(PPh<sub>3</sub>)<sub>4</sub> (5 mol %) in THF for 1 day gave

corresponding alkyl-allyl products **4a**, **4b** and **4c**, respectively, in good yields (entries 1, 2, and 3). As a result of extensive examination of various allyl compounds, we found that the  $\alpha,\beta$ -unsaturated carbonyl compounds **1** with allylic acetates **3** proceeded very smoothly at room temperature in the presence of Pd(PPh<sub>3</sub>)<sub>4</sub> catalyst in THF to give the corresponding  $\beta$ -alkylated and  $\alpha$ -allylated products **4** in high yields. Treatment of tricyclohexylborane **2b**, which made in situ, with **1a** under the normal conditions gave the desired products (**4d-f**) in good to moderate yield (entry 4-6). However the reaction of acrolein **1b**, methyl vinyl ketone **1c** and 2-cyclohexen-1-one **1d**, which bear no substituent at  $\beta$  position, gave the desired products **4g**, **4h** and **4i** in 37%, 27% and 12% yield (entries 7, 8 and 9). These poor yields indicate that the radical unstableness of the intermediate **5** which are not attached R<sup>5</sup> group at  $\beta$  position. The sterical bulky olefin **1e**, derived from Meldrum's acid, gave only the alkylated product **4j** in 50% yield (entry 10).

According to transfer an alkyl group for producing  $\beta$ -alkylation of  $\alpha,\beta$ -unsaturated carbonyl compound **1**, the reaction reported that it involved a free-radical mechanism.<sup>5</sup> Under this free-radical mechanism regarding the alkylation, it was expected for the  $\alpha$ -allylation *via*  $\pi$ -allylpalladium that the reaction continuously proceeds the same path through the initially formed intermediate of the enol borinate **5** (eq. 2). Although the exact path of the mechanism involving the free-radical reaction is still unclear, some clues may be



**Table 1.**  $\beta$ -Alkyl- $\alpha$ -allylation of  $\alpha,\beta$ -unsaturated carbonyl compounds<sup>a</sup>

Entry	Olefin (1)	Trialkylborane (2)	Allyl compound (3)	Product (4)	Yield (%) <sup>b</sup>
1					86 <sup>c</sup>
2	1a	2a			84
3	1a	2a			81
4	1a		3a		70
5	1a	2b	3b		73
6	1a	2b	3c		53
7		2a	3a		37
8		2a	3a		27
9		2a	3a		12
10			3a		50
	1e	2c		4j	

<sup>a</sup>Unless otherwise noted, all the reactions were conducted with olefin (0.8 mmol), trialkylborane (0.88 mmol) and allyl compound (2.0 mmol) in the presence of Pd(PPh<sub>3</sub>)<sub>4</sub> (5 mol %) in 1.5 mL THF at rt for 1 d.

<sup>b</sup>Yields were obtained after purification by column chromatography.

<sup>c</sup>Tributylborane contains 6% *sec*-butyl group and the addition product have 6% of *sec*-butyl group.

revealed that the better reaction yield depends on the  $\beta$ -alkylation procedure by trialkylboranes and a problem of dropping in products yield arise where the intermediate **5**

have the order of radical stability,<sup>6</sup> when using  $\alpha,\beta$ -unsaturated carbonyl compounds which are not attached R<sup>5</sup> group.

In conclusion, we have developed an easy synthetic methodology to make double-added products of the olefins in a direct process by palladium catalyzed reaction. In these reactions, the use of  $\alpha,\beta$ -unsaturated carbonyl compounds with trialkylboranes would afford smoothly alkylated intermediates **5** under neutral conditions. Directly, palladium catalyzed reaction with **5** gave the corresponding  $\beta$ -alkyl and  $\alpha$ -allylated products. The ordinary coupling reactions by organoboron compounds was utilized for the three-component coupling reactions.

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- General Procedure: An oven-dried 5 mL conical reaction vial containing a magnetic spin vane with argon inlet was charged with 1.2 equiv of tributylborane **2a** (0.88 mmol), 1.5 mL of freshly distilled THF and a  $\alpha,\beta$ -unsaturated carbonyl compound **1a-e** (0.8 mmol). For using tricyclohexylborane **2d**, an oven-dried 10mL branched round flask, fitted with an inlet carrying a rubber septum cap, a magnetic stirring bar, and a condenser, was flushed with argon. In the flask was charged with 0.88 mmol of borane in 2 mL of THF. Then cyclohexene (2.64 mmol) was added and the mixture was stirred at 50 °C for 3 hr to ensure completion of this exceptionally sluggish hydroboration. Another oven-dried vial was charged with 0.5 mol % Pd(PPh<sub>3</sub>)<sub>4</sub> (0.04 mmol), 2 equiv. of allyl acetate (1.6 mmol), 1.5 mL of THF for completely dissolved solution. To the colorless solution containing trialkylborane was added the yellow solution containing palladium catalyst at room temperature. After being stirred for 1 day, the reaction mixture was filtered through a short silica gel column chromatography using ether as an eluent, and the filtrate was concentrated. the reaction was washed with cold H<sub>2</sub>O (3 × 15 mL), followed by three portions 15 mL of H<sub>2</sub>O saturated with sodium chloride. The organic layer was separated and the aqueous layer was extracted with diethyl ether (3 × 10 mL). The combined organic extracts were dried over anhydrous MgSO<sub>4</sub> and were concentrated in vacuum to give a crude oil. The crude product was purified via column chromatography with a mixed solvent (*n*-Hexane/EtOAc, 10/1).