Rhodium-catalysed substitutive arylation of *cis*-allylic diols with arylboroxines†

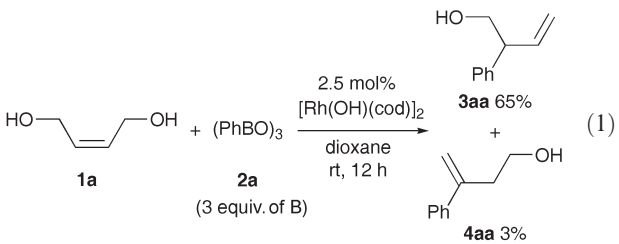
Tomoya Miura, Yusuke Takahashi and Masahiro Murakami*

Received (in Cambridge, UK) 4th September 2006, Accepted 20th October 2006
First published as an Advance Article on the web 8th November 2006
DOI: 10.1039/b612710j

Substitutive arylation of *cis*-allylic diols occurs upon treatment with arylboroxines in the presence of a rhodium(I) catalyst; the reaction proceeds through the addition of an intermediate arylrhodium(I) species across the carbon–carbon double bond and subsequent β-oxygen elimination.

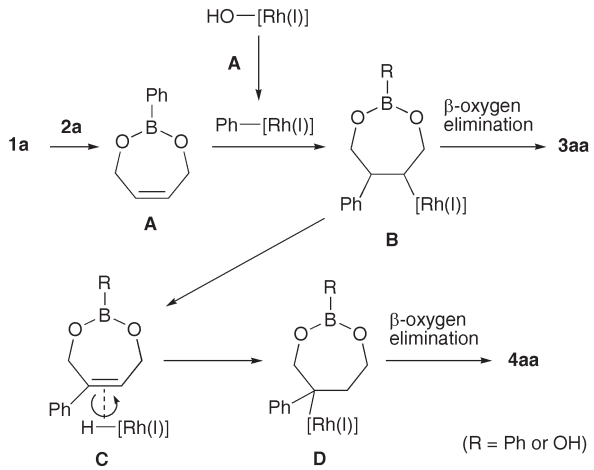
The rhodium-catalysed addition of organoborons to alkenes and alkynes has emerged as a powerful method for the construction of carbon–carbon bonds.[1] Although alkenes are generally less reactive than alkynes, activated examples, such as electron-deficient[2] and strained[3] alkenes, act as good acceptors of organorhodium(I) intermediates. In aqueous media, styrene derivatives also react with organoborons.[4] We have been trying to expand the scope of rhodium-catalysed addition and have found a new example of the alkene addition reaction. Herein, we report the rhodium-catalysed substitutive arylation of *cis*-allylic diols with arylboroxines.

A solution of *cis*-but-2-ene-1,4-diol (**1a**) and phenylboroxine (**2a**, 3.0 equiv. of B) in 1,4-dioxane (0.1 M) was stirred in the presence of $[Rh(OH)(cod)]_2$ (5 mol% Rh, cod = cycloocta-1,5-diene) at room temperature for 12 h. After chromatography, 2-phenylbut-3-en-1-ol (**3aa**) was isolated in 65% yield, together with a small amount of 3-phenylbut-3-en-1-ol (**4aa**, *ca.* 3%; eqn. 1). Other organoborons, like phenylboronic acid and its glycol ester, gave lower yields.



(1)

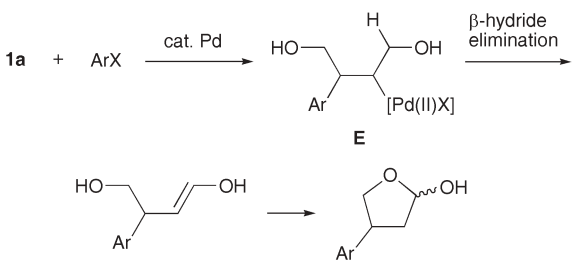
When **1a** (0.16 mmol) was mixed with **2a** (0.16 mmol, 3 equiv. of B) in 1,4-dioxane-d_8 (1 mL) in the absence of rhodium catalyst, the spontaneous formation of cyclic arylboronic ester **A**[5] *via* transesterification was observed by ^{1}H NMR.[6] We assume the stepwise pathways depicted in Scheme 1 for the reaction of **1a**.[7] Initially, cyclic arylboronic ester **A** is formed *in situ* from **1a** and **2a**. Then, transmetalation of hydroxorhodium(I) with **A** generates a phenylrhodium(I) species.[8] The phenylrhodium(I) undergoes *syn*



Scheme 1 A plausible mechanism for the catalysed addition reaction.

1,2-addition across the carbon–carbon double bond of **A**,[9] giving the alkylrhodium(I) intermediate **B**. Subsequent β-oxygen elimination occurs to generate the major product **3aa**. Another pathway is also derived from **B** that leads to the minor product **4aa**. β-Hydride elimination and re-addition with the opposite regiochemistry gives the alkylrhodium(I) intermediate **D**. The following β-oxygen elimination affords minor product **4aa**. It is of note for **B** that β-oxygen elimination predominates over β-hydride elimination.[3e,10] This is in sharp contrast to the palladium-catalysed Heck-type reaction of **1a** with aryl halide, where organopalladium(II) intermediate **E** undergoes β-hydride elimination rather than β-oxygen elimination, leading to the formation of a 4-aryltetrahydrofuran-2-ol (Scheme 2).[11,12]

A control experiment was carried out using *trans*-but-2-ene-1,4-diol, which is unlikely to be transformed into the corresponding cyclic arylboronic ester. The reaction was sluggish at room temperature, giving only a trace amount of **3aa** after 12 h. In



Scheme 2 The palladium-catalysed Heck-type reaction of *cis*-allylic diol **1a** with aryl halide.

Department of Synthetic Chemistry and Biological Chemistry, Kyoto University, Katsura, Kyoto 615-8510, Japan.
E-mail: murakami@sbchem.kyoto-u.ac.jp; Fax: +81 75 383 2748; Tel: +81 75 383 2747

† Electronic supplementary information (ESI) available: Experimental details and spectral data. See DOI: 10.1039/b612710j

Table 1 Rhodium-catalysed substitutive arylation of *cis*-allylic diol **1a** with arylboroxines or an alkenylboroxine **2**[a]

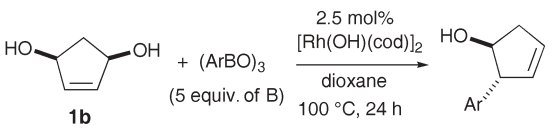
Entry	**2** (R)	**3**	Yield (%)[b]
1	**2b** (4-Me–C_6H_4)	**3ab**	69[c]
2	**2c** (4-F–C_6H_4)	**3ac**	52[c]
3	**2d** (3-MeO–C_6H_4)	**3ad**	81
4	**2e** (3-Cl–C_6H_4)	**3ae**	77[c]
5	**2f** (1-Naphthyl)	**3af**	81
6	**2g** (Ph)	**3ag**	22[c,d]

[a] Unless otherwise noted, all reactions were carried out with **1a** (0.55 mmol), **2** (0.55 mmol) and $[Rh(OH)(cod)]_2$ (5 mol% Rh) in dioxane (5 mL) at rt for 12–24 h. [b] Isolated yield. [c] 5 equiv. of B was used. [d] 60 °C.

addition, no reaction occurred when *cis*-non-2-en-1-ol was used as the substrate. These results indicate that formation of the cyclic arylboronic ester **A** facilitates the 1,2-addition of a phenylrhodium(I) species. The use of other substrates **5–7**, which were derived from *cis*-but-2-ene-1,4-diol, was also examined. However, these substrates failed to participate in the substitutive reaction.

A variety of arylboroxines and an alkenylboroxine **2** were subjected to the substitutive arylation of *cis*-allylic diol **1a** (Table 1).[13]‡ Both electron-donating and -withdrawing aromatic substituents were suitably reactive (Table 1, entries 1–4). In the case of sterically bulkier 1-naphthylboroxine (**2f**), the corresponding product **3af** was obtained in 81% yield (Table 1, entry 5). However, alkenylboroxine **2g** produced compound **3ag** in only 22% yield (Table 1, entry 6).

We next examined the reaction with cyclic *cis*-allylic diol **1b**. When *cis*-cyclopent-4-ene-1,3-diol (**1b**) was treated with phenylboroxine (**2a**, 5.0 equiv. of B) at 100 °C for 24 h, *trans*-2-phenylcyclopent-3-en-1-ol (**3ba**, 46%) was obtained in a regio- and stereoselective manner (eqn. 2). The reaction of **1b** with 3-methoxyphenylboroxine (**2d**) gave the *trans*-isomer **3bd** stereoselectively in 70% yield. The *trans* stereochemistry of the arylated products can be explained by assuming that the *syn* 1,2-addition of an arylrhodium(I) species across a carbon–carbon double bond occurs from opposite sides of the hydroxyl groups and that β-oxygen elimination proceeds in an *anti* fashion.[10a]



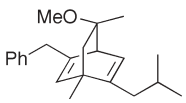
(2)

Since 2-aryl-3-en-1-ols are versatile synthons that can be further manipulated in a stereo- and chemoselective way, the asymmetric version of the substitutive arylation was briefly examined (Table 2). In the case of (*S*)-BINAP (**8**), which is highly effective for the rhodium-catalysed asymmetric addition of arylboronic acids to electron-deficient alkenes,[2b] both the yield and the enantioselectivity were modest (55% yield, 41% ee; Table 2, entry 1). The use of chiral diene ligand **9**, developed by Carreira *et al.*,[14] improved both the chemical yield and the enantioselectivity (68% yield, 83% ee; Table 2, entry 2). The highest enantioselectivity was observed when 1-naphthylboroxine (**2f**) was used (87% ee; Table 2, entry 4). Analogous reaction conditions were applied to cyclic allylic diol **1b** to give **3bd** (78% ee; Table 2, entry 5).[15]

Table 2 Asymmetric arylative addition catalysed by a rhodium(I) complex[a]

Entry	**1**	**2** (R)	Ligand	**3**	Yield (%)[b]	ee (%)[c]
1	**1a**	**2a** (Ph)	**8**	**3aa**	55	41
2	**1a**	**2a** (Ph)	**9**	**3aa**	68	83
3	**1a**	**2d** (3-MeO–C_6H_4)	**9**	**3ad**	62	53
4	**1a**	**2f** (1-Naphthyl)	**9**	**3af**	60[d,e]	87
5	**1b**	**2d** (3-MeO–C_6H_4)	**9**	**3bd**	57[f]	78

[a] Unless otherwise noted, all reactions were carried out with **1** (0.55 mmol), **2** (0.92 mmol), $[RhCl(C_2H_4)_2]_2$ (5 mol% Rh), chiral ligand (5.5 mol%) and KOH (0.28 mmol) in dioxane (5 mL) at 40 °C for 2 d. [b] Isolated yield. [c] Determined by a Chiralcel OD-H column. [d] H_2O (1.5 equiv.) was added. [e] 60 °C. [f] 100 °C.



9

In summary, we have developed a rhodium-catalysed addition reaction of arylboroxines with *cis*-allylic diols, allowing the regio- and stereoselective formation of 2-aryl-3-en-1-ols.[16]

This work was supported in part by a Grant-in-Aid for Young Scientists (B) (no. 18750084) from the Ministry of Education, Culture, Sports, Science, and Technology, Japan.

Notes and references

‡ *Representative procedure*: To an oven-dried, Ar-purged flask was added phenylboroxine (**2a**, 176.5 mg, 0.57 mmol, 3.0 equiv. of B) and $[Rh(OH)(cod)]_2$ (6.5 mg, 0.014 mmol, 5 mol% Rh). Then, a solution of substrate **1a** (48.9 mg, 0.56 mmol) in 1,4-dioxane (5 mL) was added. The resulting reaction mixture was stirred for 12 h at room temperature. An aqueous solution of 2 M NaOH (6 mL) was added and the aqueous layer was extracted with diethyl ether (4 × 15 mL). The combined extracts were dried over $MgSO_4$. The solvent was removed under reduced pressure and the residue purified by preparative thin-layer chromatography (hexane : ethyl acetate = 5 : 3) to give the product **3aa** (53.8 mg, 0.36 mmol) in 65% yield.

1 Reviews: (*a*) K. Fagnou and M. Lautens, *Chem. Rev.*, 2003, **103**, 169; (*b*) T. Hayashi and K. Yamasaki, *Chem. Rev.*, 2003, **103**, 2829.
2 (*a*) M. Sakai, H. Hayashi and N. Miyaura, *Organometallics*, 1997, **16**, 4229; (*b*) T. Hayashi, M. Takahashi, Y. Takaya and M. Ogasawara, *J. Am. Chem. Soc.*, 2002, **124**, 5052; (*c*) R. Shintani, W.-L. Duan and T. Hayashi, *J. Am. Chem. Soc.*, 2006, **128**, 5628 and references cited therein.
3 (*a*) K. Oguma, M. Miura, T. Satoh and M. Nomura, *J. Am. Chem. Soc.*, 2000, **122**, 10464; (*b*) M. Lautens, C. Dockendorff, K. Fagnou and A. Malicki, *Org. Lett.*, 2002, **4**, 1311; (*c*) M. Murakami and H. Igawa, *Chem. Commun.*, 2002, 390; (*d*) T. Miura and M. Murakami, *Org. Lett.*, 2005, **7**, 3339; (*e*) T. Miura, T. Sasaki, T. Harumashi and M. Murakami, *J. Am. Chem. Soc.*, 2006, **128**, 2516; (*f*) N.-W. Tseng, J. Mancuso and M. Lautens, *J. Am. Chem. Soc.*, 2006, **128**, 5338.
4 M. Lautens, A. Roy, K. Fukuoka, K. Fagnou and B. Martín-Matute, *J. Am. Chem. Soc.*, 2001, **123**, 5358.
5 An authentic sample of ester **A** was prepared by reacting **1a** with phenylboronic acid in benzene in the presence of $MgSO_4$ as a dehydrating agent.
6 N. Iwasawa, T. Kato and K. Narasaka, *Chem. Lett.*, 1988, 1721.

7 For the rhodium-catalysed cross-coupling of allyl alcohols with arylboronic acid *via* a π-allylrhodium intermediate, see: G. W. Kabalka, G. Dong and B. Venkataiah, *Org. Lett.*, 2003, **5**, 893.
8 Direct transmetalation with **2a** may also occur.
9 The use of isolated **A** as the substrate gave product **3aa** in 61% yield.
10 (*a*) M. Murakami and H. Igawa, *Helv. Chim. Acta*, 2002, **85**, 4182; (*b*) L. Navarre, S. Darses and J.-P. Genet, *Chem. Commun.*, 2004, 1108; (*c*) T. Miura, M. Shimada and M. Murakami, *J. Am. Chem. Soc.*, 2005, **127**, 1094; (*d*) L. Dong, Y.-J. Xu, L.-F. Cun, X. Cui, A.-Q. Mi, Y.-Z. Jiang and L.-Z. Gong, *Org. Lett.*, 2005, **7**, 4285.
11 T. Mandai, S. Hasegawa, T. Fujimoto, M. Kawada, J. Nokami and J. Tsuji, *Synlett*, 1990, 85.
12 For related reactions, see: (*a*) A. J. Chalk and S. A. Magennis, *J. Org. Chem.*, 1976, **41**, 273; (*b*) S. Torii, H. Okumoto, F. Akahoshi and T. Kotani, *J. Am. Chem. Soc.*, 1989, **111**, 8932; (*c*) A. Arcadi, E. Bernocchi, S. Cacchi and F. Marinelli, *Tetrahedron*, 1991, **47**, 1525; (*d*) S. Takano, K. Samizu and K. Ogasawara, *Synlett*, 1993, 393.
13 An excess amount of **2** was required to obtain a good yield, as is often the case for rhodium-catalysed reactions using arylboronic acids.
14 (*a*) J.-F. Paquin, C. Defieber, C. R. J. Stephenson and E. M. Carreira, *J. Am. Chem. Soc.*, 2005, **127**, 10850; Review: (*b*) F. Glorius, *Angew. Chem., Int. Ed.*, 2004, **43**, 3364.
15 For the transition-metal catalysed desymmetrisation of cyclic allylic diol derivatives, see: U. Piarulli, P. Daubos, C. Claverie, C. Monti and C. Gennari, *Eur. J. Org. Chem.*, 2005, 895 and references cited therein.
16 During the submission of our manuscript, Lautens and co-workers reported the rhodium-catalysed desymmetrisation of a dicarbonate of *cis*-cyclopent-4-ene-1,3-diol: F. Menard, T. M. Chapman, C. Dockendorff and M. Lautens, *Org. Lett.*, 2006, **8**, 4569.