Organic LETTERS

Letter

pubs.acs.org/OrgLett

Boron-Selective Biaryl Coupling Approach to Versatile Dibenzoxaborins and Application to Concise Synthesis of Defucogilvocarcin M

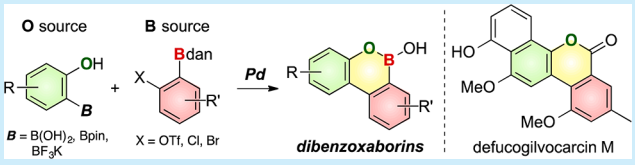
Yuto Sumida,[†,§] Ryu Harada,[†] Tomoe Kato-Sumida,[†,§] Kohei Johmoto,[‡] Hidehiro Uekusa,[‡] and Takamitsu Hosoya*[,†]

[†]Laboratory of Chemical Bioscience, Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University, 2-3-10 Kanda-Surugadai, Chiyoda-ku, Tokyo 101-0062, Japan

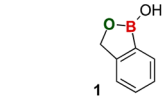
[‡]Department of Chemistry and Materials Science, Graduate School of Science and Engineering, Tokyo Institute of Technology, 2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8551, Japan

Supporting Information

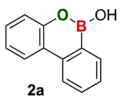
ABSTRACT: An efficient synthetic method for versatile dibenzoxaborins based on boron-selective Suzuki–Miyaura cross-coupling between *o*-borylphenols and aryl halides or triflates bearing a 1,8-diaminonaphthalene-protected *o*-boryl group is reported. A short synthesis of defucogilvocarcin M was achieved using the proposed method in combination with several other boron-mediated transformations.



Organoboron compounds play valuable roles in a variety of disciplines, e.g., as efficient building blocks in organic synthesis and materials science and as unique pharmacophores and chemosensors in medicinal chemistry and chemical biology.[1] Recently, considerable attention has been paid to cyclic boronic half esters, such as 1,3-dihydro-1-hydroxy-2,1-benzoxaborole (**1**), because of their superior properties in terms of binding affinity to saccharides[2] and bioactivity.[3] 6-Hydroxy-6*H*-dibenz[*c*,*e*][1,2]oxaborin (**2a**),[4] which is referred to as dibenzoxaborin in this paper, is a cyclic boronic half ester that serves as a useful building block for constructing versatile π-conjugated systems.[5] Typically, dibenzoxaborins have been prepared by treatment of 2-hydroxybiaryl with BCl_3 followed by addition of $AlCl_3$[4a,b,5a] or a monohalogen–lithium exchange reaction of 2,2′-dibromobiaryl followed by treatment with a trialkyl borate.[5b] However, only limited dibenzoxaborins are available from the reported synthetic methods,[4−6] and the utility of dibenzoxaborins remains largely unexplored. Herein, we show an efficient synthetic method for dibenzoxaborins that is based on boron-selective Suzuki–Miyaura cross-coupling.



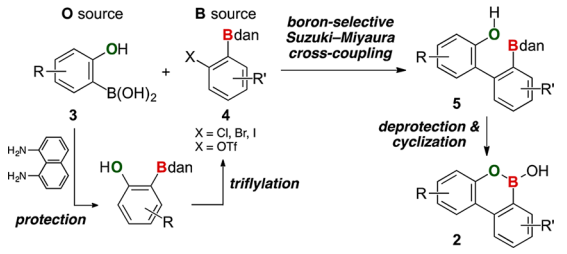
1
1,3-dihydro-1-hydroxy-2,1-benzoxaborole



2a
6-hydroxy-6*H*-dibenz[*c*,*e*][1,2]oxaborin
(referred to as dibenzoxaborin)

Dibenzoxaborins **2** contain a biphenyl substructure; therefore, we conceived the idea of preparing **2** using Suzuki–Miyaura cross-coupling[7] of *ortho*-hydroxyaryl boronic acid **3** with aryl halide **4** bearing a 1,8-diaminonaphthalene (dan)-protected *ortho*-boryl group,[8] followed by deprotection of the dan group and intramolecular dehydrative cyclization (Scheme 1). We assumed that this strategy would be suitable for preparing diverse dibenzoxaborins because the oxygen source **3** could be transformed into triflate-type boron source **4** (X = OTf) by a simple two-step procedure: dan-protection of the boryl group and triflylation of the phenolic hydroxy group.

Scheme 1. Synthetic Plan of Dibenzoxaborins based on Boron-Selective Suzuki–Miyaura Cross-coupling

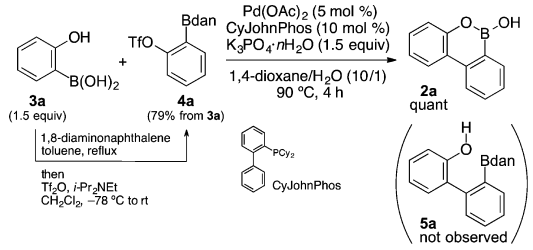


After extensive screening of the reaction conditions for cross-coupling of (2-hydroxyphenyl)boronic acid (**3a**) with dan-protected *ortho*-borylphenyl triflate **4a**, an excellent result was obtained using CyJohnPhos[8b,9] as a ligand for the catalytic system and potassium phosphate as a base (Scheme 2).[10,11] Contrary to our expectation, the originally intended cross-coupling product **5a** was not obtained; however, the desired dibenzoxaborin **2a** was produced directly without special manipulations. This result was possibly because of the high affinity of oxygen for boron, which assisted deprotection of the dan group and formation of a stable dibenzoxaborin skeleton. Furthermore, we observed that using an equimolar amount of

Received: October 31, 2014
Published: November 24, 2014

dx.doi.org/10.1021/ol5031734 | *Org. Lett.* 2014, 16, 6240–6243

Scheme 2. Optimized Conditions



base with an arylboronic acid was important to obtain dibenzoxaborin in high yield.[10] The reaction conditions using an excess amount of base significantly decreased the product yield accompanying the production of 2-phenylphenol, which should be formed through protodeborylation of dibenzoxaborin **2a** triggered by the redundant base.

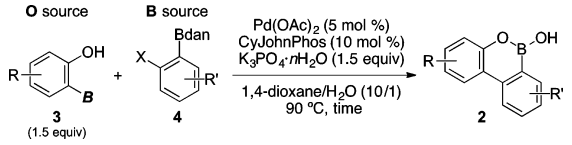
Under the optimized conditions, a variety of O-sources **3** and B-sources **4** with either electron-donating or -withdrawing groups served as good substrates to afford dibenzoxaborins, including those difficult to prepare by conventional methods (Table 1). As for the oxygen source, not only boronic acids but also boronic acid pinacol esters or a trifluoroborate salt[12] were usable under the same conditions (entries 1, 4–7, 12). In particular, a $Pd(PPh_3)_4$ catalytic system gave better results for some pinacol ester substrates (entries 1, 5, 6). These results significantly increased the scope of the method because a variety of *o*-hydroxyarylboronic acid pinacol esters can be readily prepared in several ways: treatment of *o*-lithiated phenolates with trialkyl borate,[13] Pd-catalyzed Miyaura borylation of *o*-halophenols,[14] or iridium-catalyzed direct *o*-borylation of phenols.[15] In addition to aryl triflates, chlorides and bromides with a neighboring Bdan group served as an efficient boron source substrate (entries 8–11, 13–15). The method enabled facile synthesis of disubstituted dibenzoxaborins and a heteroatom containing compound, such as pyridine-fused benzoxaborin **2m** (entries 11–13). Unique pentacyclic arylboronic ester **2n** was also available via double cyclization of dibromo boron source **4g** using an excess amount of **3a** (entry 14). The planar structure of **2n** was clearly demonstrated by X-ray structure analysis.[10,16] Coupling of olefinic boron source **4h** with **3a** proceeded in the same fashion, providing benzoxaborin **2o** in high yield (entry 15).

Moreover, trading the boryl group of the oxygen source with the halogen group of the boron source was effective for the synthesis of bis(dibenzoxaborin) derivative **2p** with a binaphthyl skeleton, which was achieved under modified conditions (Scheme 3).[10,17] Coupling of 3,3′-dibromo-[1,1′-binaphthalene]-2,2′-diol (**6**) with monodan-protected *ortho*-benzenediboronic acid pinacol ester **7**[8b] using di(1-adamantyl)-*n*-butylphosphine[18] as a ligand afforded **2p** in moderate yield.[10,19]

The boron-selective coupling approach was also applicable to the synthesis of dihydrodibenzazaborine[20] derivatives using *ortho*-borylated anilines as a nitrogen source (Scheme 4A). Cross-coupling of (2-aminophenyl)boronic acid (**8a**) with **4a** under the general conditions afforded dihydrodibenzazaborine **9**[5a,20a,b,d] in 70% yield. The reaction of (2-(acetylamino)phenyl) boronic acid (**8b**) with **4a** afforded the cross-coupling product **10**, wherein the Bdan group remained untouched. This was probably due to the low nucleophilicity of amide nitrogen. In this case, the catalytic system using $Pd(amphos)_2Cl_2$[21] provided a better result. Removal of the dan group of **10** under acidic conditions and purification by recrystallization afforded dehydrated dimer **11** as the sole product in high yield (Scheme 4B).[10,16,20c]

The utility of the synthetic method for dibenzoxaborins was demonstrated in a short synthesis of defucogilvocarcin M (**12**), taking advantage of other boron-mediated transformations

Table 1. Scope of Substrates

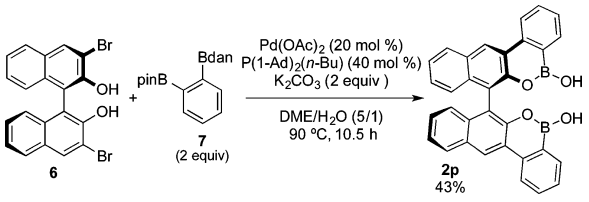


entry	**O** source **3**[a]	**B** source **4**	time (h)	product **2**	yield (%)[b]
1	**3b**	**4a**	8 (5)[c]	**2a**	74 (98)[c]
2	**3c**	**4a**	5	**2b**	88
3	**3d**	**4a**	4	**2c**	67
4	**3e**	**4a**	5	**2d**	92
5	**3f**	**4a**	4 (9)[c]	**2e**	78 (92)[c]
6	**3g**	**4a**	4 (9)[c]	**2f**	56 (74)[c]
7	**3h**	**4a**	4	**2g**	72
8	**3a**	**4b**	4	**2h**	92
9	**3a**	**4c**	4	**2i**	80
10	**3a**	**4d**	2	**2j**	83
11	**3c**	**4d**	3.5	**2k**	89
12	**3e**	**4e**	5	**2l**	85
13	**3a**	**4f**	16	**2m**	65
14[d]	**3a**	**4g**	9	**2n**	30
15	**3a**	**4h**	5	**2o**	81

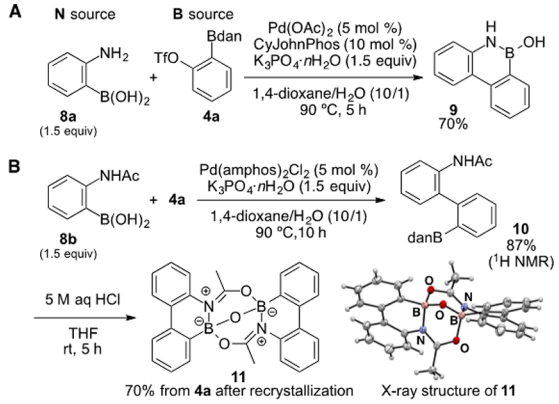
[a]Bpin = 4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl. [b]Isolated yields. [c]Reaction times and yields for the reaction performed using $Pd(PPh_3)_4$ (5 mol %) and 2 M aqueous Na_2CO_3 (1.5 equiv) in DME at 90 °C in parentheses. [d]Molar ratio: **3a**/**4g**/base = 3.0/1.0/1.5.

dx.doi.org/10.1021/ol5031734 | *Org. Lett.* 2014, 16, 6240–6243

Scheme 3. Bis(dibenzoxaborin) with Binaphthyl Skeleton



Scheme 4. Synthesis of Dihydrodibenzazaborines[a]



[a]amphos = *p*-$(Me_2N)C_6H_4P(t\text{-}Bu)_2$.

(Scheme 5). Defucogilvocarcin M is a representative aglycon of the gilvocarcin-class antibiotics, which have been considered as a challenging synthetic target by many groups.[22] A previous report has shown that dibenzoxaborin is capable of converting into 3,4-benzocoumarin by a palladium-mediated deborylative CO insertion reaction.[5a] Thus, we assumed that defucogilvocarcin M with a dibenzocoumarin structure can be prepared from benzonaphthoborin with appropriate substituents, such as **2q**. Therefore, we first prepared the coupling components, 2-boryl-1-naphthol derivative **3i** and triflate **4i**.

The oxygen source **3i** was prepared from known naphthol **16**[23] by iridium-catalyzed *ortho*-borylation[15] (Scheme 5A). Previously, Suzuki and co-workers reported an efficient approach to differentially protected 1,4,5-naphthalenetriol **16** based on regioselective [2 + 4]-cycloaddition of 3-benzyloxybenzyne with 2-methoxyfuran.[23] Recently, we have reported an efficient generation method for arynes via ate complexes of arylboronic esters bearing an *ortho*-triflyloxy group.[24] This method was also effective for the regioselective synthesis of naphthol **16** using aryne precursor **15**, which was easily prepared by *ortho*-borylation[15] of 2-benzyloxyphenol (**13**) and subsequent triflylation. The boron source **4i** was similarly prepared by *ortho*-borylation and triflylation of 4-methylguaiacol (**17**), followed by a simple two-step conversion of the pinacolatoboryl group to the dan-protected boryl group (Scheme 5B).

Synthesis of defucogilvocarcin M was accomplished in three additional steps (Scheme 5C). Boron-selective Suzuki–Miyaura cross-coupling of **3i** with **4i** afforded the desired benzonaphthoborin **2q** in 86% yield. Palladium-mediated deborylative CO insertion of **2q** provided dibenzocoumarin derivative **20**.[22l] Finally, debenzylation of **20** under reported conditions[22l] afforded defucogilvocarcin M (**12**). The synthesis was accomplished in 7 steps with a 39% overall yield in the longest linear sequence, which compares very favorably with the previous successful syntheses: 17% in 11 steps,[22h] 31% in 8 steps,[22i] 33% in 8 steps,[22j] 33% in 16 steps,[22l] and 15% in 9 steps[22m] (some of them do not include the yields for the preparation of starting materials).

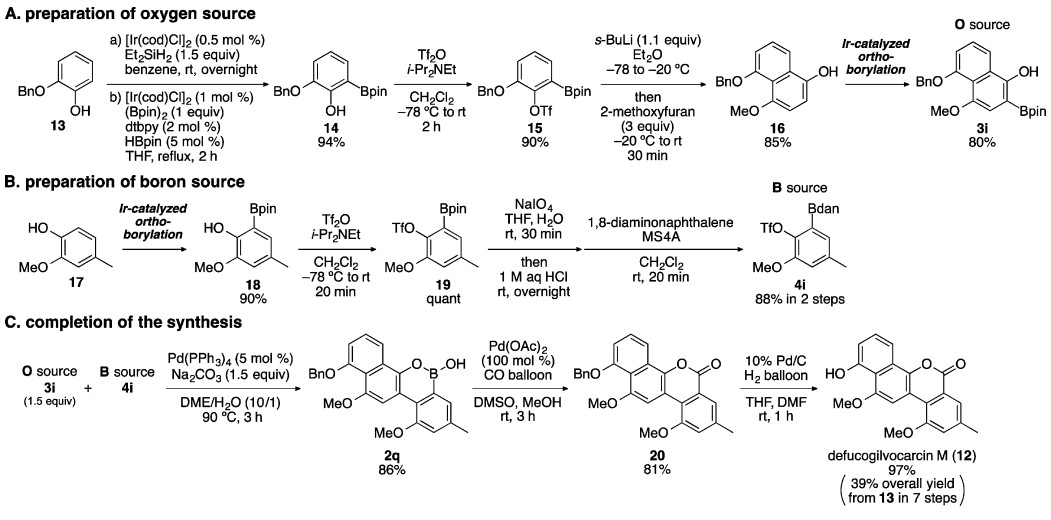
In summary, we have developed a convenient synthetic method for diverse dibenzoxaborin derivatives. The method was successfully applied to the concise synthesis of defucogilvocarcin M. Further studies on dibenzoxaborins, including their application to novel transformations and molecular recognition, are currently in progress.

■ ASSOCIATED CONTENT

Supporting Information

Experimental procedures and characterization data including copies of NMR spectra and the X-ray crystallographic data. This material is available free of charge via the Internet at http://pubs.acs.org.

Scheme 5. Synthesis of Defucogilvocarcin M Using Boron-Mediated Transformations[a]



[a]cod = cyclooctadiene, dtbpy = 4,4′-di-*tert*-butyl-2,2′-bipyridyl.

dx.doi.org/10.1021/ol5031734 | *Org. Lett.* 2014, 16, 6240–6243

AUTHOR INFORMATION

Corresponding Author

*E-mail: thosoya.cb@tmd.ac.jp.

Present Address

[§]Chemical Biology Team, Imaging Chemistry Group, Division of Bio-Function Dynamics Imaging, RIKEN Center for Life Science Technologies (CLST), 6-7-3 Minatojima-minamimachi, Chuo-ku, Kobe 650-0047, Japan.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors thank Ms. Ayako Hosoya at Tokyo Medical and Dental University for HRMS analyses, and Central Glass Co., Ltd. for their generous gift of Tf_2O. This work was supported by Platform for Drug Discovery, Informatics, and Structural Life Science from MEXT, Japan; JSPS KAKENHI Grant Number 24651257 (T.H.); and the Terumo Life Science Foundation (Y.S.).

REFERENCES

(1) (a) James, T. D.; Sandanayake, K. R. A. S.; Shinkai, S. *Angew. Chem., Int. Ed.* **1996**, *35*, 1910. (b) Ni, N.; Wang, B. Applications of Boronic Acids in Chemical Biology and Medicinal Chemistry. In *Boronic Acids: Preparation and Applications in Organic Synthesis, Medicine and Materials*, 2nd ed.; Hall, D. G., Ed.; Wiley-VCH: Weinheim, 2011; Vol. *1*, pp 591–620. (c) Yamaguchi, S.; Wakamiya, A. *Pure Appl. Chem.* **2006**, *78*, 1413. (d) James, T. D., Philips, M. D.; Shinkai, S. *Boronic acids in saccharide recognition*; RSC Publishing: Cambridge, 2006. (e) Jin, S.; Cheng, Y.; Reid, S.; Li, M.; Wang, B. *Med. Res. Rev.* **2010**, *30*, 171. (f) Fossey, J. S.; D'Hooge, F.; van den Elsen, J. M. H.; Morais, M. P. P.; Pascu, S. I.; Bull, S. D.; Marken, F.; Jenkins, A. T. A.; Jiang, Y.-B.; James, T. D. *Chem. Rec.* **2012**, *120*, 464.

(2) (a) Dowlut, M.; Hall, D. G. *J. Am. Chem. Soc.* **2006**, *128*, 4226. (b) Bérubé, M.; Dowlut, M.; Hall, D. G. *J. Org. Chem.* **2008**, *73*, 6471. (c) Ellis, G. A.; Palte, M. J.; Raines, R. T. *J. Am. Chem. Soc.* **2012**, *134*, 3631.

(3) (a) Rock, F. L.; Mao, W.; Yaremchuk, A.; Tukalo, M.; Crépin, T.; Zhou, H.; Zhang, Y.-K.; Hernandez, V.; Akama, T.; Baker, S. J.; Plattner, J. J.; Shapiro, L.; Martinis, S. A.; Benkovic, S. J.; Cusack, S.; Alley, M. R. K. *Science* **2007**, *316*, 1759. (b) Seiradake, E.; Mao, W.; Hernandez, V.; Baker, S. J.; Plattner, J. J.; Alley, M. R. K.; Cusack, S. *J. Mol. Biol.* **2009**, *390*, 196. (c) Pal, A.; Bérubé, M.; Hall, D. G. *Angew. Chem., Int. Ed.* **2010**, *49*, 1492. (d) Zajdlik, A.; Wang, Z.; Hickey, J. L.; Aman, A.; Schimmer, A. D.; Yudin, A. K. *Angew. Chem., Int. Ed.* **2013**, *52*, 8411. (e) Knack, D. H.; Marshall, J. L.; Harlow, G. P.; Dudzik, A.; Szaleniec, M.; Liu, S.-Y.; Heider, J. *Angew. Chem., Int. Ed.* **2013**, *52*, 2599.

(4) (a) Dewar, M. J. S.; Dietz, R. *Tetrahedron Lett.* **1959**, 21. (b) Dewar, M. J. S.; Dietz, R. *J. Chem. Soc.* **1960**, 1344. (c) Davis, F. A.; Dewar, M. J. S. *J. Org. Chem.* **1968**, *33*, 3324. (d) Greig, L. M.; Kariuki, B. M.; Habershon, S.; Spencer, N.; Johnston, R. L.; Harris, K. D. M.; Philp, D. *New J. Chem.* **2002**, *26*, 701. For some related compounds, see: (e) Grisdale, P. J.; Williams, J. L. R. *J. Org. Chem.* **1969**, *34*, 1675. (f) Maringgele, W.; Meller, A.; Noltemeyer, M.; Sheldrick, G. M. *Z. Anorg. Allg. Chem.* **1986**, *536*, 24. (g) Arcus, V. L.; Main, L.; Nicholson, B. K. *J. Organomet. Chem.* **1993**, *460*, 139. (h) Chen, J.; Bajko, Z.; Kampf, J. W.; Ashe, A. J., III. *Organometallics* **2007**, *26*, 1563.

(5) (a) Zhou, Q. J.; Worm, K.; Dolle, R. E. *J. Org. Chem.* **2004**, *69*, 5147. (b) He, J.; Crase, J. L.; Wadumethrige, S. H.; Thakur, K.; Dai, L.; Zou, S.; Rathore, R.; Hartley, C. S. *J. Am. Chem. Soc.* **2010**, *132*, 13848. (c) Mathew, S. M.; Engle, J. T.; Ziegler, C. J.; Hartley, C. S. *J. Am. Chem. Soc.* **2013**, *135*, 6714.

(6) Dohi, T.; Kamitanaka, T.; Watanabe, S.; Hu, Y.; Washimi, N.; Kita, Y. *Chem.—Eur. J.* **2012**, *18*, 13614.

(7) (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457. (b) Suzuki, A.; Brown, H. C. *Organic Syntheses via Boranes: Suzuki Coupling, Vol. 3*; Aldrich: Milwaukee, 2003.

(8) (a) Noguchi, H.; Hojo, K.; Suginome, M. *J. Am. Chem. Soc.* **2007**, *129*, 758. (b) Noguchi, H.; Shioda, T.; Chou, C.-M.; Suginome, M. *Org. Lett.* **2008**, *10*, 377.

(9) (a) Wolfe, J. P.; Buchwald, S. L. *Angew. Chem., Int. Ed.* **1999**, *38*, 2413. (b) Wolfe, J. P.; Singer, R. A.; Yang, B. H.; Buchwald, S. L. *J. Am. Chem. Soc.* **1999**, *121*, 9550.

(10) See Supporting Information for details.

(11) Attempts for coupling reaction using B sources without dan protection were unsuccessful. See Supporting Information for details.

(12) (a) Molander, G. A.; Ellis, N. *Acc. Chem. Res.* **2007**, *40*, 275. (b) Darses, S.; Genet, J.-P. *Chem. Rev.* **2008**, *108*, 288.

(13) Friedman, A. A.; Panteleev, J.; Tsoung, J.; Huynh, V.; Lautens, M. *Angew. Chem., Int. Ed.* **2013**, *52*, 9755.

(14) Ishiyama, T.; Murata, M.; Miyaura, N. *J. Org. Chem.* **1995**, *60*, 7508.

(15) Boebel, T. A.; Hartwig, J. F. *J. Am. Chem. Soc.* **2008**, *130*, 7534.

(16) The X-ray crystallographic data for compounds **2n** (CCDC 1020935) and **11** (CCDC 1020936) can be obtained free of charge from the Cambridge Crystallographic Data Centre (CCDC) via www.ccdc.cam.ac.uk/data_request/cif.

(17) Attempts for cross-coupling of 2-bromophenol with **7** resulted in a low yield of **2a** (approximately 10% yield) even with the use of any of the catalytic systems including $Pd(PPh_3)_4$, $Pd(OAc)_2$/CyJohnPhos, $Pd(OAc)_2$/P(1-Ad)$_2$(*n*-Bu), and Pd[P(*t*-Bu)$_3$]$_2$.

(18) (a) Zapf, A.; Ehrentraut, A.; Beller, M. *Angew. Chem., Int. Ed.* **2000**, *39*, 4153. (b) Rueping, M.; Sugiono, E.; Steck, A.; Theissmann, T. *Adv. Synth. Catal.* **2010**, *352*, 281.

(19) The cross-coupling of 3,3′-bis(pinacolatoboryl)-[1,1′-binaphthalene]-2,2′-diol with **4a** (2 equiv) gave only a trace amount of **2p** even with the use of any of the catalytic systems such as $Pd(PPh_3)_4$, $Pd(OAc)_2$/CyJohnPhos, and P(1-Ad)$_2$(*n*-Bu).

(20) (a) Dewar, M. J. S.; Kubba, V. P.; Pettit, R. *J. Chem. Soc.* **1958**, 3073. (b) Dewar, M. J. S.; Dewar, R. B. K.; Gaibel, Z. L. F. *Org. Synth.* **1966**, *46*, 65. (c) Komorowska, M.; Niedenzu, K.; Weber, W. *Inorg. Chem.* **1990**, *29*, 289. (d) Harris, K. D. M.; Kariuki, B. M.; Lambropoulos, C.; Philp, D.; Robinson, J. M. A. *Tetrahedron* **1997**, *53*, 8599. For some related compounds, see: (e) Paetzold, P.; Stanescu, C.; Stubenrauch, J. R.; Bienmüller, M.; Englert, U. *Z. Anorg. Allg. Chem.* **2004**, *630*, 2632. (f) Molander, G. A.; Wisniewski, S. R. *J. Org. Chem.* **2014**, *79*, 8339 and references cited therein.

(21) Guram, A. S.; King, A. O.; Allen, J. G.; Wang, X.; Schenkel, L. B.; Chan, J.; Bunel, E. E.; Faul, M. M.; Larsen, R. D.; Martinelli, M. J.; Reider, P. J. *Org. Lett.* **2006**, *8*, 1787.

(22) For the total synthesis of gilvocarcins, see: (a) Matsumoto, T.; Hosoya, T.; Suzuki, K. *J. Am. Chem. Soc.* **1992**, *114*, 3568. (b) Hosoya, T.; Takashiro, E.; Matsumoto, T.; Suzuki, K. *J. Am. Chem. Soc.* **1994**, *116*, 1004. (c) Futagami, S.; Ohashi, Y.; Imura, K.; Hosoya, T.; Ohmori, K.; Matsumoto, T.; Suzuki, K. *Tetrahedron Lett.* **2000**, *41*, 1063. For the synthesis of defucogilvocarcins, see: (d) Findlay, J. A.; Daljeet, A.; Murray, P. J.; Rej, R. N. *Can. J. Chem.* **1987**, *65*, 427. (e) McKenzie, T. C.; Hassen, W.; Macdonald, S. J. F. *Tetrahedron Lett.* **1987**, *28*, 5435. (f) Patten, A. D.; Nguyen, N. H.; Danishefsky, S. J. *J. Org. Chem.* **1988**, *53*, 1003. (g) McGee, L. R.; Confalone, P. N. *J. Org. Chem.* **1988**, *53*, 3695. (h) Jung, M. E.; Jung, Y. H. *Tetrahedron Lett.* **1988**, *29*, 2517. (i) Hart, D. J.; Merriman, G. H. *Tetrahedron Lett.* **1989**, *30*, 5093. (j) Deshpande, P. P.; Martin, O. R. *Tetrahedron Lett.* **1990**, *31*, 6313. (k) James, C. A.; Snieckus, V. *Tetrahedron Lett.* **1997**, *38*, 8149. (l) Takemura, I.; Imura, K.; Matsumoto, T.; Suzuki, K. *Org. Lett.* **2004**, *6*, 2503. (m) James, C. A.; Snieckus, V. *J. Org. Chem.* **2009**, *74*, 4080. (n) Cortezano-Arellano, O.; Cordero-Vargas, A. *Tetrahedron Lett.* **2010**, *51*, 602. (o) Nandaluru, P. R.; Bodwell, G. J. *J. Org. Chem.* **2012**, *77*, 8028. (p) Pahari, P.; Kharel, M. K.; Shepherd, M. D.; van Lanen, S. G.; Rohr, J. *Angew. Chem., Int. Ed.* **2012**, *51*, 1216.

(23) Matsumoto, T.; Hosoya, T.; Katsuki, M.; Suzuki, K. *Tetrahedron Lett.* **1991**, *32*, 6735.

(24) Sumida, Y.; Kato, T.; Hosoya, T. *Org. Lett.* **2013**, *15*, 2806.