Facile Synthesis of Dendralenes Based on the Cross-coupling Reaction of 2,3-Bis(pinacolato)boryl-1,3-butadiene

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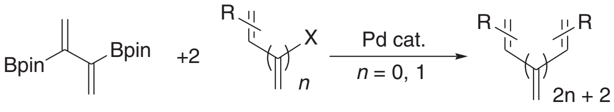
(Received June 7, 2004; CL-040652)

Palladium-catalyzed cross-coupling reaction of 2,3-diboryl-1,3-butadiene with an alkenyl halide or a dienyl halide allowed us to straightforwardly prepare various kinds of acyclic cross-conjugated polyenes that are referred to as dendralenes. The present method is applicable to the synthesis of not only symmetrical [4]- and [6]dendralenes but also unsymmetrical [3]- to [5]dendralenes.

Growing interest has been paid to cyclic cross-conjugated molecules such as radialenes and fulvenes in view of not only their unique electronic structures and properties but also their potential as novel key fragments of conjugated organic materials.[1] In contrast, acyclic cross-conjugated counterpart dendralenes have remained unexplored probably because of limited synthetic methods.[2] Therefore, a convenient and straightforward method for synthesis of dendralenes has been awaited to promote studies on their structures, reactivities, and electronic properties.

We have recently reported that alkylidene-type lithium carbenoids react with diborons to afford 1,1-diboryl-1-alkenes efficiently.[3] The method can be extended to the preparation of 2,3-bis(pinacolato)boryl-1,3-butadienes (**1**, Bpin: (pinacolato)-boryl).[4] We envisioned that dendralenes could be prepared conveniently if alkenyl halides would act as a good coupling partner with **1** in the presence of a palladium catalyst.[5] Herein reported is a facile synthesis of dendralenes via coupling reaction of **1** with alkenyl bromides and iodides (Eq 1).[6]

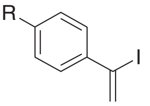
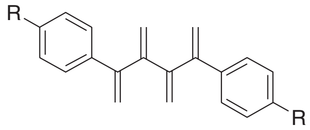
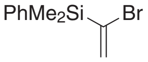
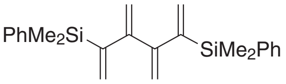
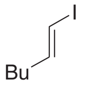
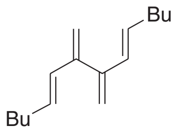
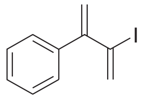
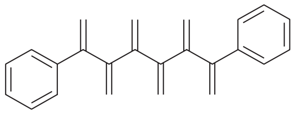


(1)

1 **2** **3**

At first, we studied coupling reaction of **1** with 3 molar amounts of α-bromostyrene in the presence of a palladium catalyst and a base. After several attempts, use of $\mathrm{Pd[P(}t\text{-}\mathrm{Bu)_3]_2}$ and KOH aqueous solution at 50 °C was found effective for the coupling reaction, giving rise to 3,4-bis(methylene)-2,5-diphenyl-1,5-hexadiene (**3a**) in 60% yield.[7] Reaction of α-iodostyrene (**2a**) also proceeded smoothly with **1** in THF/KOH aqueous solution even at room temperature, giving rise to **3a** in slightly better yield (Table 1, Entry 1). Coupling reaction of 1-(4-fluorophenyl)- or 1-(4-nitrophenyl)-1-iodoethene **2b** or **2c** proceeded similarly at room temperature to afford **3b** or **3c** in moderate yield, respectively (Entries 2 and 3). Symmetrical disilylated and dibutylated [4]dendralenes **3d** and **3e** were obtained when 1-bromo-1-(dimethylphenylsilyl)ethene (**2d**) and (*E*)-1-iodohex-1-ene (**2e**) were employed as a coupling partner (Entries 4 and 5). In addition, [6]dendralene **3f** was isolated as the sole product in 32% yield after purification by column chromatography on silica gel, when 2-iodo-3-phenyl-1,3-butadiene (**2f**) was coupled at room temperature in the presence of $\mathrm{Pd_2(dba)_3}$ (5 mol %), $\mathrm{P(}t\text{-}\mathrm{Bu)_3}$ (20 mol %), and KOH aqueous solution (Entry 6).

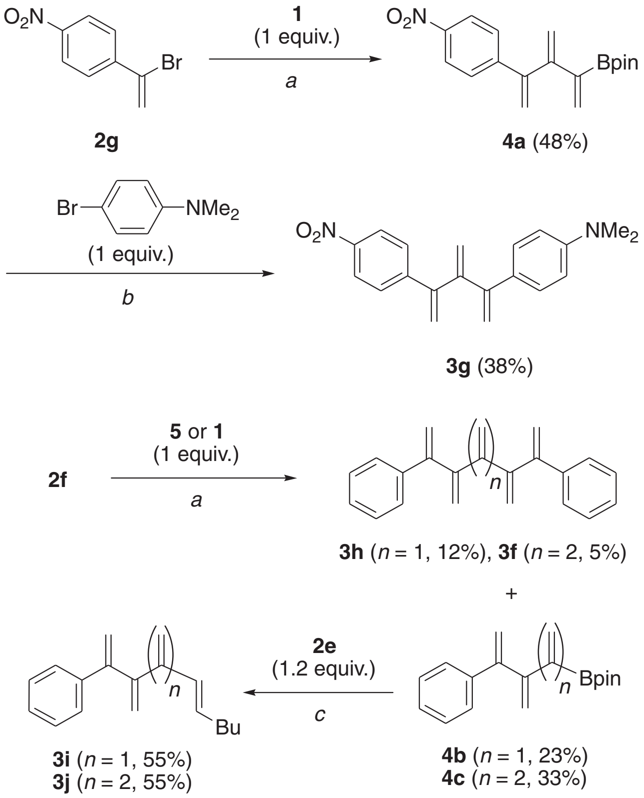
Table 1. Synthesis of symmetrical dendralenes[a]

Entry	**2**	**3** (yield/%)[b]
		
1	**2a** (R = H)	**3a** (63)
2	**2b** (R = F)	**3b** (47)
3	**2c** (R = NO_2)	**3c** (31)
4	 **2d**	 **3d** (37)
5	 **2e**	 **3e** (58)
6	 **2f**	 **3f** (32)

[a] Coupling reaction of **1** (1 molar amount) and alkenyl halide **2** (3 molar amounts) was carried out in THF under the following conditions: for Entry 1, $\mathrm{Pd_2(dba)_3}$ (10 mol %)/$\mathrm{P(}t\text{-}\mathrm{Bu)_3}$ (20 mol %), KOH aq, rt; for Entries 2 and 3, $\mathrm{Pd_2(dba)_3}$ (5 mol %)/$\mathrm{P(}t\text{-}\mathrm{Bu)_3}$ (20 mol %), KOH aq, rt; for Entry 4, $\mathrm{Pd[P(}t\text{-}\mathrm{Bu)_3]_2}$ (10 mol %), KOH aq, 50 °C; for Entry 5, $\mathrm{Pd_2(dba)_3}$ (3 mol %)/$\mathrm{P(}t\text{-}\mathrm{Bu)_3}$ (6 mol %), KOH aq, 40 °C; for Entry 6, $\mathrm{Pd_2(dba)_3}$ (5 mol %)/$\mathrm{P(}t\text{-}\mathrm{Bu)_3}$ (20 mol %), KOH aq, rt. [b] Isolated yield.

To prepare unsymmetrical dendralenes, **1** was treated with an equimolar amount of an alkenyl halide. In this case, a combination of Cs_2CO_3 aqueous solution and 1,4-dioxane was found more effective than the THF/KOH aq system to obtain mono-coupling product selectively. Thus, coupling reaction of **2g** with **1** under the conditions afforded **4a** in 48% yield along with **3c** in

5% yield (Scheme 1). Trienyl- and tetraenylboronates **4b** and **4c** were obtained as a major product from **2f** and 1,1-bis(pinacolato)borylethene (**5**)[3] or **1**, although the yields remain yet to be improved. Palladium-catalyzed coupling reaction of **4a** with 4-(dimethylamino)bromobenzene gave [3]dendralene **3g** consisting of a donor–π–acceptor electronic structure. Unsymmetrical [4]- and [5]dendralenes **3i** and **3j** were synthesized from **4b** and **4c** with **2e**, respectively.



Scheme 1. Synthesis of unsymmetrical [3]- to [5]dendralenes. Conditions a: Pd[P(t-Bu)$_3$] (10 mol %), Cs_2CO_3 aq (3 equiv.), 1,4-dioxane, 50 °C. Conditions b: Pd(OAc)$_2$ (10 mol %), PPh$_3$ (40 mol %), KOH aq (3 equiv.), 1,4-dioxane, 80 °C. Conditions c: Pd[P(t-Bu)$_3$] (10 mol %), KOH aq (3 equiv.), THF, 50 °C.

The UV spectra of 2,3-diphenyl-1,3-butadiene, **3a**, and **3f** measured in cyclohexane (1×10^{-5} M) at room temperature show absorption maxima of 2,3-diphenyl-1,3-butadiene at 243 nm ($\varepsilon = 24200$), **3a** at 231 nm ($\varepsilon = 42600$), and **3f** at 225 nm ($\varepsilon = 30000$), blue shift in proportion to the number of carbon–carbon double bonds, indicating that the exo methylenes prefer a twisted conformation rather than a coplanar one.[8]

Further studies on preparation and properties of dendralenes are in progress.

This work was supported by Grant-in-Aid for COE Research on Elements Science, No. 12CE2005, and for Young Scientists (B), No. 14750678 from Ministry of Education, Culture, Sports, Science and Technology, Japan. Japan Society for the Promotion of Science (JSPS) is highly acknowledged for the financial support to T. K. as a predoctoral research student.

References and Notes

1 a) H. Hopf, "Classics in Hydrocarbon Chemistry," Wiley-VCH, Weinheim (2000), p 251. b) H. Hopf and G. Maas, *Angew. Chem., Int. Ed. Engl.*, **31**, 931 (1992).

2 Review: a) H. Hopf, *Angew. Chem., Int. Ed. Engl.*, **23**, 948 (1984). Recent example: b) S. Fielder, D. D. Rowan, and M. S. Sherburn, *Angew. Chem., Int. Ed.*, **39**, 4331 (2000). See also, c) H. Hopf, *Angew. Chem., Int. Ed.*, **40**, 705 (2001). Cross-conjugated system with enynes as a recurring unit: d) R. R. Tykwinski and F. Diederich, *Liebigs Ann./Recl.*, **1997**, 649. e) Y. Zhao and R. R. Tykwinski, *J. Am. Chem. Soc.*, **121**, 458 (1999). f) R. R. Tykwinski and Y. Zhao, *Synlett*, **2002**, 1939. 1,3-Dithio-2-ylidene-containing cross-conjugated molecules: g) Y. Misaki, Y. Matsumura, T. Sugimoto, and Z. Yoshida, *Tetrahedron Lett.*, **30**, 5289 (1989). h) M. R. Bryce, M. A. Coffin, P. J. Skabara, A. J. Moore, A. S. Batsanov, and J. A. K. Howard, *Chem.—Eur. J.*, **6**, 1955 (2000). i) M. B. Nielsen, N. F. Utesch, N. N. P. Moonen, C. Boudon, J.-P. Gisselbrecht, S. Concilio, S. P. Piotto, P. Seiler, P. Günter, M. Gross, and F. Diederich, *Chem.—Eur. J.*, **8**, 3601 (2002). j) T. Kumagai, M. Tomura, J.-i. Nishida, and Y. Yamashita, *Tetrahedron Lett.*, **44**, 6845 (2003).

3 a) T. Hata, H. Kitagawa, H. Masai, T. Kurahashi, M. Shimizu, and T. Hiyama, *Angew. Chem., Int. Ed.*, **40**, 790 (2001). b) T. Kurahashi, T. Hata, H. Masai, H. Kitagawa, M. Shimizu, and T. Hiyama, *Tetrahedron*, **58**, 6381 (2002).

4 M. Shimizu, T. Kurahashi, and T. Hiyama, *Synlett*, **2001**, 1006.

5 Reviews of Suzuki-Miyaura coupling reaction: a) N. Miyaura and A. Suzuki, *Chem. Rev.*, **95**, 2457 (1995). b) A. Suzuki, *J. Organomet. Chem.*, **576**, 147 (1999). c) A. Suzuki, in "Metal-Catalyzed Cross-Coupling Reactions," ed. by F. Diederich and P. J. Stang, Wiley-VCH, Weinheim (1998), p 49. d) "Cross-Coupling Reaction: A Practical Guide," Springer-Verlag, Berlin (2002), Vol. 219, p 11.

6 Sherburn reported cross-coupling reaction of 2,3-bis(trimethylstannyl)-1,3-butadiene with 3-iodo-3-sulfolene followed by thermolysis at 450 °C, giving rise to [6]dendralene and [8]dendralene. See Ref. 2b.

7 Typical procedure: To a solution of **1** (20 mg, 0.066 mmol) and Pd[P(t-Bu)$_3$]$_2$ (3.4 mg, 0.0066 mmol) in THF (0.7 mL) was added α-bromostyrene (26 µL, 0.20 mmol) and 6 M KOH aq solution (66 µL) at room temperature. The resulting mixture was stirred at 50 °C for 6 h before quenching with saturated NH_4Cl aqueous solution. The aqueous layer was extracted with ethyl acetate (three times). The combined organic layer was washed with saturated NaCl aq solution, dried over anhydrous $MgSO_4$, and concentrated under reduced pressure. The crude product was purified with preparative silica gel TLC (hexane/ethyl acetate 10:1) to give **3a** (10 mg, 60%) as a colorless oil. R$_f$ 0.55 (hexane/ethyl acetate 10:1). ^{1}H NMR ($CDCl_3$) δ 5.18 (d, $J = 2.0$ Hz, 2H), 5.30 (d, $J = 2.0$ Hz, 2H), 5.32 (d, $J = 1.6$ Hz, 2H), 5.40 (d, $J = 1.6$ Hz, 2H), 7.28–7.33 (m, 10H). ^{13}C NMR ($CDCl_3$) δ 115.9, 119.1, 127.4, 127.5, 128.0, 140.6, 148.8, 149.2. IR (neat) 3088, 3055, 3024, 1585, 1576, 1493, 1445, 1028, 905, 779, 698 cm^{-1}. EIMS (70 eV) m/z 258 (M$^+$, 99), 257 (M$^+$ – 1, 100), 229 (20), 165 (27), 128 (26), 115 (26), 91 (24), 77 (Ph$^+$, 19). HRMS Calcd for $C_{20}H_{18}$: M$^+$, 258.1409. Found: m/z 258.1408.

8 a) P. T. Brain, B. A. Smart, H. E. Robertson, M. J. Davis, D. W. H. Rankin, W. J. Henry, and I. Gosney, *J. Org. Chem.*, **62**, 2767 (1997). b) M. H. Palmer, J. A. Blair-Fish, and P. Sherwood, *J. Mol. Struct.*, **412**, 1 (1997).

Published on the web (Advance View) July 24, 2004; DOI 10.1246/cl.2004.1066