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Cascade Triple-Aldehyde Addition of 1,2,3,4-Tetrakis(pinacolatoboryl)but-2-ene: Stereoselective Synthesis of 2,3-Bis(alkylidene)alkane-1,5-diols

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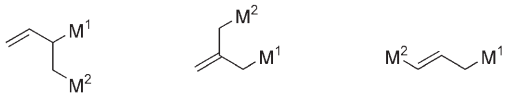
Dedicated to Professor Miguel Yus on the occasion of his 60th birthday

Abstract: Treatment of (*Z*)-1,2,3,4-tetrakis(pinacolatoboryl)but-2-ene, prepared from 2,3-bis(pinacolatoboryl)buta-1,3-diene and bis(pinacolato)diboron, with three molar equivalents of aldehyde in toluene at 100 °C gave the 2,3-bis(alkylidene)alkane-1,5-*anti*-diol as a single stereoisomer. The reaction is applicable to both aromatic and α-unbranched aliphatic aldehydes. The 1,5-*anti*-diols were also synthesized by the one-pot preparation/triple-aldehyde addition of the tetraborylated butene. Experimental results for the stepwise treatment of the butene with two types of aldehydes suggest that the rate-determining step of the triple-aldehyde addition is the third allylation.

Keywords: allylation · boron · diastereoselectivity · domino reactions · synthesis design

Introduction

From the economic and environmental viewpoints, much of the attention of synthetic chemists has been paid to cascade reactions that involve two or more bond-forming transformations and that construct complex molecular frameworks from simple substrates by a single synthetic operation in one reaction vessel. These reactions save time, money, and resources as well as minimize waste by avoiding reaction setup, workup, and purification of products in each step.[1] Meanwhile, as allyl metal compounds are extremely versatile reagents for carbon–carbon bond formation in organic synthesis,[2] metalated allyl metals such as α- and β-(metalomethyl)-substituted and γ-metalated compounds (**1**–**3**; Scheme 1) constitute an attractive class of reagents for cascade reactions, because the initial γ-selective allylation generates an allyl metal functionality in the products.[3] For example, 1-silylmethyl allylic silane **1a** ($M^1 = SiMePh_2$, $M^2 = SiMe_2Ph$) was reported to undergo a one-pot double Sakurai–Hosomi reaction with aliphatic aldehydes to give 2,3,5-trisubstituted tetrahydrofurans.[3d] Treatment of aldimines with 2-silylmethyl allylic stannane **2a** ($M^1 = SnBu_3$, $M^2 = SiMe_3$) in the presence of chlorotrimethylsilane followed by the addition of aldehydes produced 2,6-*cis*-disubstituted piperidines stereoselectively.[3p] γ-Borylated allylic borane **3a** (M^1 = diisopinocampheylboryl, M^2 = 1,3,2-dioxaborinanyl) was found to react with two molecules of aldehydes to give both *syn*- and *anti*-alkane-1,5-diols with high diastereo- and enantioselectivities, respectively, in a one-pot operation.[3e] These types of dimetalated compounds can also act as versatile precursors of polyfunctional organometallic reagents.[4]



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Scheme 1. Monometalated allyl metals for cascade reactions.

During the course of our study on the preparation and synthetic applications of dimetalated compounds,[5] we succeeded in the facile and stereoselective synthesis of (*Z*)-1,2,3,4-tetrakis(pinacolatoboryl)but-2-ene (**4**) by platinum-catalyzed 1,4-diboration of 2,3-bis(pinacolatoboryl)buta-1,3-diene (**5**) with bis(pinacolato)diboron (**6**).[6] As **4** can be regarded as a double hybrid of type **3** and that the efficiency of cascade reactions can be correlated with the number of bonds and stereocenters formed in the sequence as well as an increase in molecular complexity, we became interested in the multiple-aldehyde allylation of **4**. This process should enhance the synthetic utility of metalated allyl metals as a

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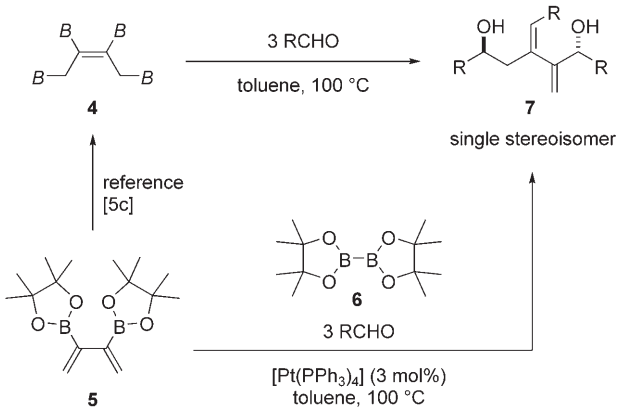
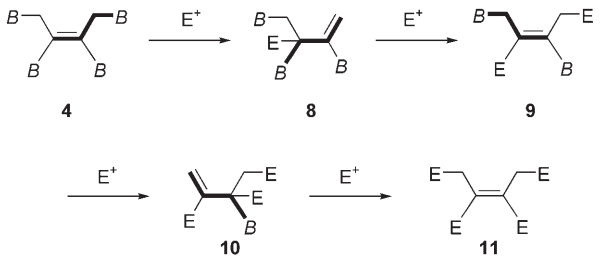
reagent for cascade reactions and provide a novel synthetic methodology that utilizes tetrametalated reagents in organic synthesis. Herein, we report a novel cascade reaction of **4** with aldehydes that produces stereochemically pure 2,3-bis(alkylidene)alkane-1,5-*anti*-diols **7** in good yields (Scheme 2).[7] The one-pot synthesis of **7** from **5** is also described.



Scheme 2. Triple-aldehyde addition of **4** leading to 1,5-*anti*-diols **7**. *B* = pinacolatoboryl.

Results and Discussion

Our hypothetical cascade scheme, which employs **4**, is shown in Scheme 3. When **4** is treated with an electrophile (E^+), **4** may react with E^+ in an S_E2' fashion to give α-(borylmethyl)-β-boryl allylborane reagent **8**, which can also react with another E^+ to give γ-boryl allylborane **9**. A further two allylborylation reactions may produce quadruply substituted (*Z*)-but-2-enes **11** in a one-pot manner.



Scheme 3. Plan for cascade quadruple allylation with **4**.

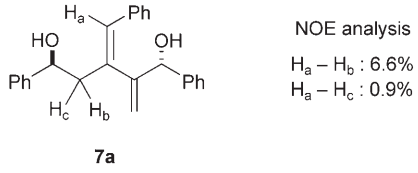
Accordingly, we employed an aldehyde as the reaction partner of **4**. The results are shown in Table 1. A solution of **4** in toluene and 4 equivalents of benzaldehyde were heated at 100 °C for 14 h to give **7a** (R = Ph) in 86% yield as a single stereoisomer, which turned out to be a 1:3 adduct instead of the expected product (**11**: E = CH(OH)Ph; Table 1, entry 3). The same reaction upon heating at 50 °C did not take place at all (Table 1, entry 1), whereas **7a** was obtained in lower yield (30–71%) when the reaction was effected in toluene at 80 °C (Table 1, entry 2) or in polar solvents such as 1,2-dichloroethane (Table 1, entry 4) and 1,4-dioxane (Table 1, entry 5) at 100 °C. Polar solvents may retard the coordination of the aldehyde to the boryl group, a process essential for carbonyl allylation of allylboronates under thermal conditions.

Table 1. Benzaldehyde addition of **4** under thermal conditions.

Entry	Solvent	*T* [°C]	Yield [%][a]
1	toluene	50	0
2	toluene	80	57
3	toluene	100	86
4	1,2-dichloroethane	100	71
5	1,4-dioxane	100	30

[a] Yield of isolated product based on **4**.

The structure of **7a** was determined by ^1H and ^{13}C NMR and IR spectroscopy, as well as elemental analysis. The configuration of the trisubstituted alkene was assigned as *Z* by an NOE experiment as summarized in Scheme 4. Although **7a** was not stable enough for the parent peak to be observed with EI MS, the structure of its diacetate **7a′**, prepared by acetylation with Ac_2O (Equation (1); DMAP = 4-dimethylaminopyridine), was confirmed by HRMS.



Scheme 4. Stereochemical assignment of trisubstituted alkene **7a**.

(1)

The diastereomeric purity of **7a** with regard to 1,5-remote stereochemistry was confirmed by comparing its ^1H and ^{13}C NMR spectra with those of a *syn*/*anti* = 1:1 diastereomeric mixture of **7a** (Figures 1 and 2), which was prepared

Abstract in Japanese:

2,3-ビス（ピナコラートボリル）-1,3-ブタジエンとビス（ピナコラート）ジボロンから調製した(*Z*)-1,2,3,4-テトラキス（ピナコラートボリル）-2-ブテンとアルデヒド3当量を溶媒トルエン中100℃に加熱すると，1:3付加体である2,3-ビス（アルキリデン）アルカン-1,5-ジオールが単一立体異性体として収率よく生成した。この反応は芳香族および脂肪族アルデヒドの両方に適用することができる。テトラボリルブテンの調製と三重アルデヒド付加を同一反応容器中で一挙におこなうことも可能である。2種類のアルデヒドを順次作用させた実験の結果から，三重アルデヒド付加の律速段階は三つ目の付加反応であると考えられる。

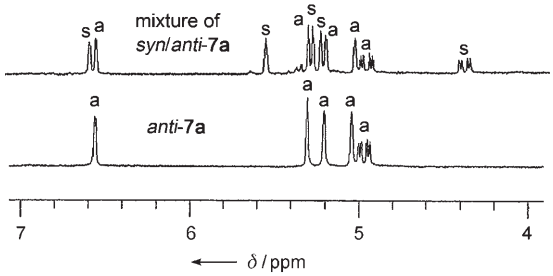


Figure 1. ^{1}H NMR spectra of **7a**. s = Signals assigned to the *syn* isomer, a = signals assigned to the *anti* isomer.

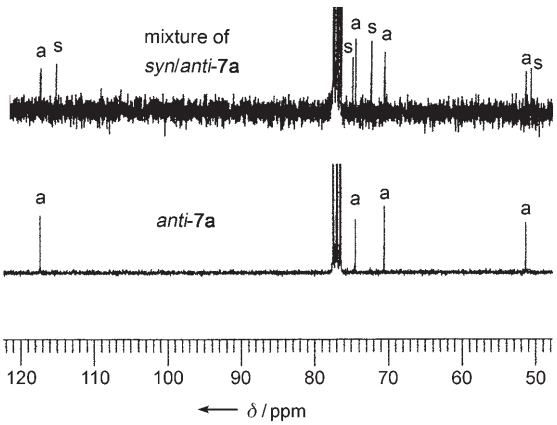
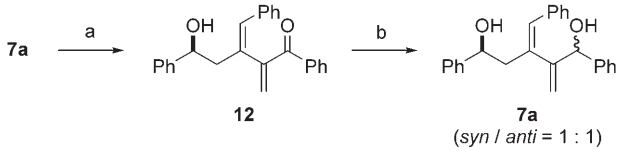


Figure 2. ^{13}C NMR spectra of **7a**. s = Signals assigned to the *syn* isomer, a = signals assigned to the *anti* isomer.

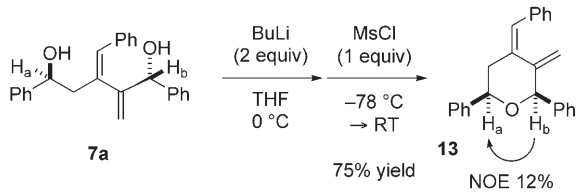
by chemoselective oxidation of allylic alcohol in **7a** with MnO_2, followed by 1,2-reduction of the resulting α,β-unsaturated ketone **12** with $NaBH_4$ in the presence of $CeCl_3{\cdot}7H_2O$ (Scheme 5).



Scheme 5. Preparation of the diastereomer mixture of **7a**. Conditions: a) MnO_2, CH_2Cl_2, 40 °C, 84 % yield; b) $NaBH_4$, $CeCl_3{\cdot}7H_2O$, MeOH, 93 % yield.

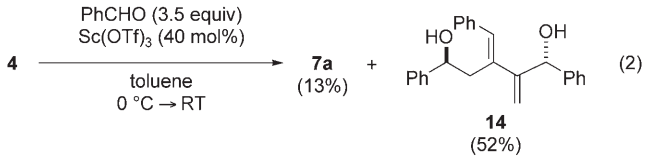
On the other hand, treatment of **7a** with 2 equivalents of BuLi followed by the addition of MsCl (1 equiv) afforded tetrahydropyran **13** as a single stereoisomer in which the two hydrogen atoms adjacent to the ether oxygen atom (H_a and H_b) are positioned *cis*, thus indicating that the 1,5-stereochemistry in **7a** is *anti* (Scheme 6).[8]

Recently, the allylation of aldehydes with allylboranes was reported to be catalyzed by a Lewis acid such as $Sc(OTf)_3$.[9] The present triple-aldehyde addition of **4** was also found to be catalyzed by $Sc(OTf)_3$ [Eq. (2)]. When the triple-aldehyde addition with benzaldehyde was carried out in toluene in the presence of $Sc(OTf)_3$ (40 mol %), **14** was



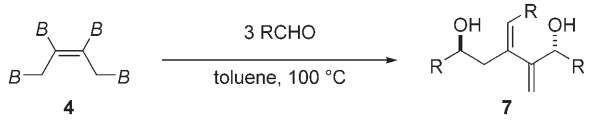
Scheme 6. Assignment of the relative 1,5-stereochemistry of **7a**. Ms = methanesulfonyl.

produced as a major product (52 % yield) along with **7a** (13 % yield). Upon UV irradiation at room temperature, pure **14** was converted into a mixture of **14** (30 %) and **7a** (70 %), and **7a** was converted into a mixture of **14** (31 %) and **7a** (53 %). These observations suggest that **14** is a 3*E* isomer of **7a** (for the mechanism of formation, see below).



This stereoselective triple-aldehyde addition under thermal conditions was applicable to a variety of aldehydes (Table 2). Aromatic aldehydes with both electron-donating and -withdrawing substituents at any position (Table 2, entries 1–8), as well as α-unbranched aliphatic aldehydes such as 3-phenylpropanal and propanal (Table 2, entries 9 and 10), underwent the cascade reaction at 100 °C smoothly and gave **7** in good yields. Whereas the addition to pivalaldehyde, methyl glyoxylate, and 2-benzyloxypropanal resulted in failure, benzyloxyacetaldehyde was found to react smoothly even at 80 °C (Table 2, entry 11). Notably, all the

Table 2. Triple-aldehyde addition of **4**.[a]



Entry	R	7	Yield [%][b]
1	C_6H_5	**7a**	86 (73)
2	4-MeO-C_6H_4	**7b**	80 (66)
3	4-C_6H_5-C_6H_4	**7c**	86 (61)
4	4-CF_3-C_6H_4	**7d**	63 (60)
5	2-naphtyl	**7e**	63 (48)
6	3-MeO-C_6H_4	**7f**	69
7	2-MeO-C_6H_4	**7g**	82 (70)
8	3,5-$(MeO)_2$-C_6H_3	**7h**	57
9	$C_6H_5(CH_2)_2$	**7i**	83
10	C_2H_5	**7j**	71
11[c]	$PhCH_2OCH_2$	**7k**	73

[a] **4** (1 equiv), RCHO (3.5 equiv), toluene, 100 °C, 11–15 h. Procedure for one-pot preparation/aldehyde addition: **5** (1 equiv), **6** (1.4 equiv), RCHO (3.5 equiv), $[Pt(PPh_3)_4]$ (3 mol %), toluene, 100 °C, 11–16 h. [b] Yield of isolated product based on **4**. The values in parentheses are the yields by the one-pot-preparation/aldehyde-addition procedure. [c] The reaction proceeded at 80 °C.

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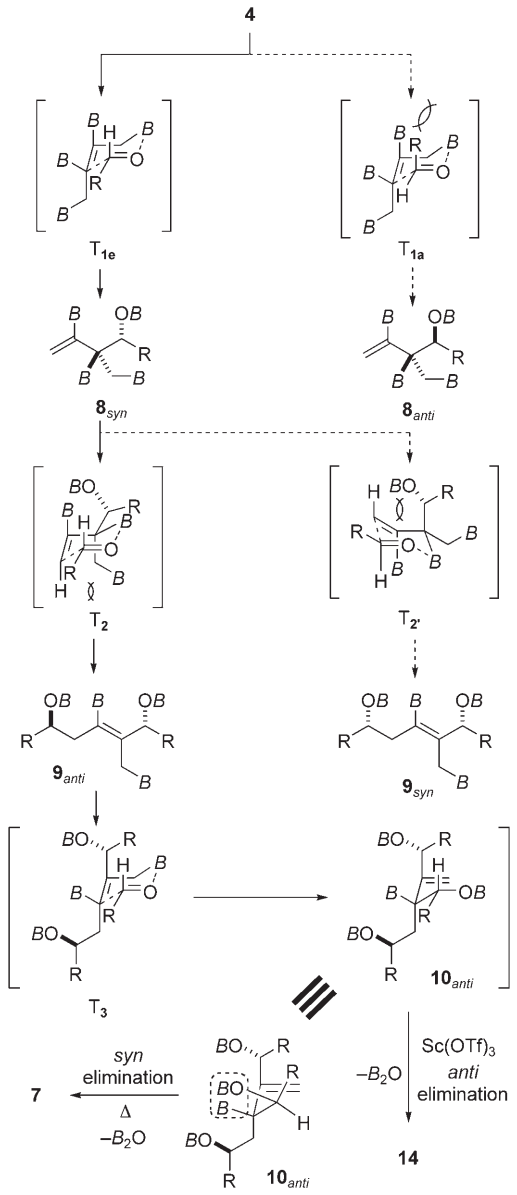
products **7a–k** were isolated as single stereoisomers, which indicates that each step of the whole transformation proceeded in a highly stereoselective manner. As a consequence, one-pot conversion of four C–B bonds into two C–C bonds and one C=C bond was attained with perfect 1,5-remote and olefinic stereocontrol.[10]

Furthermore, the triple addition can be performed in situ during the preparation of **4**. Thus, heating of a solution of 2,3-diborylbuta-1,3-diene (**5**; 1.0 equiv), bis(pinacolato)diboron (**6**; 1.4 equiv), and RCHO (3.5 equiv) in toluene in the presence of $[Pt(PPh_3)_4]$ (3 mol%) at 100 °C for 11–17 h gave **7a–e** and **7g** as single stereoisomers in acceptable yields (Table 2, entries 1–5 and 7). It is remarkable that sequential stereoselective formation of two carbon–boron bonds and three carbon–carbon bonds was cleanly achieved in a single experimental operation.

The stereochemical outcome is reasonably explained by assuming six-membered cyclic transition states, which is well-accepted for the allylation of allylic borane reagents (Scheme 7).[2] Thus, reagent **1** should react with RCHO via T_{1e}, in which the substituent R adopts an equatorial position, to give $\mathbf{8}_{syn}$. The diastereomeric transition state T_{1a} involves an axial R group and, hence, is unfavorable. The second aldehyde addition of $\mathbf{8}_{syn}$ would proceed via T_2 rather than $T_{2'}$ to produce $\mathbf{9}_{anti}$, because a 1,3-diaxial repulsion between H and CH(O*B*)R would be much more severe than that between H and CH_2*B*. The third aldehyde addition takes place from $\mathbf{9}_{anti}$ via T_3 to generate $\mathbf{10}_{anti}$, which should cause β elimination of the remaining boryl and boroxy groups in a *syn* fashion under thermal conditions to give **7** before the fourth aldehyde addition of $\mathbf{10}_{anti}$, probably owing to steric hindrance around the boryl group. On the other hand, the Lewis acid $Sc(OTf)_3$ may accelerate *anti* elimination of the boryl and boroxy groups to give **14** preferentially.

To gain insight into the rate-determining step of the triple-cascade reaction and to explore the possibility of stepwise addition to different aldehydes, we carried out the reaction of **4** with one and two molar equivalents of benzaldehyde. At first, a solution of one molar equivalent of benzaldehyde and **4** in toluene was stirred at room temperature and then gradually warmed. The reaction was monitored by TLC. Upon heating at 60 °C for 2 h, unidentified product **15** started to be observed on TLC (a tailing spot, $R_f = 0.45$, hexane/EtOAc = 1:1). The reaction mixture was then heated at 80 °C for 8 h and at 100 °C for 3 h. The spot of **4** disappeared and only that of **15** was observed on TLC. When the heating procedure was applied to the reaction of two molar equivalents of benzaldehyde with **4**, formation of **15** and **7a** was observed by TLC. After workup and purification by preparative TLC, **7a** was isolated in 44% yield, whereas **15** decomposed. Other attempts at purification of **15** by gel-permeation chromatography and silica-gel column chromatography also failed.

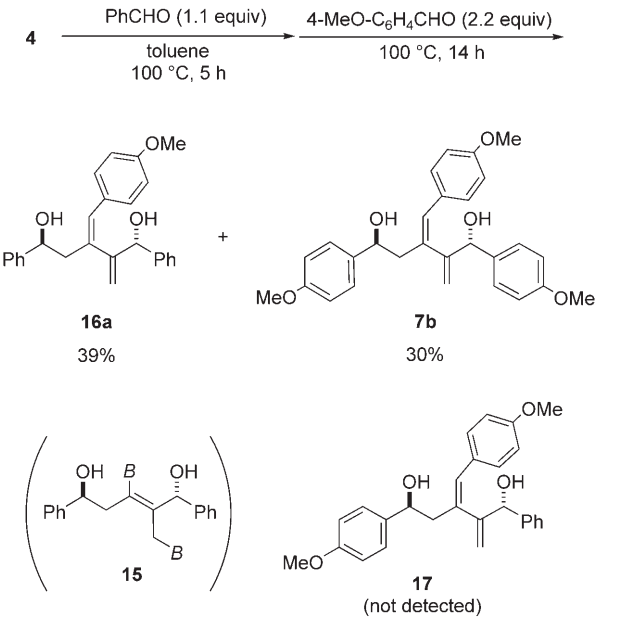
As the unidentified product **15** was difficult to isolate, we considered that one or two molar equivalents of *p*-anisaldehydes might react with **15** in the hope that an isolable product such as **7** might be obtained. A solution of **4** and one



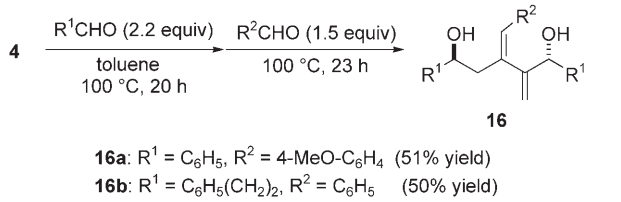
Scheme 7. Plausible mechanism for the triple-aldehyde addition of **4**.

molar equivalent of benzaldehyde in toluene was stirred at 100 °C for 5 h. Next, 2.2 molar equivalents of *p*-anisaldehyde was added, and the mixture was heated at 100 °C to give 1,5-diol **16a**, derived from two molecules of benzaldehyde and one molecule of *p*-anisaldehyde, as a single stereoisomer in 39% yield, along with **7b** in 30% yield (Scheme 8). The other possible product **17** (from one molecule of benzaldehyde and two molecules of *p*-anisaldehyde) was hardly detected. This result shows that **15** may be a 1:2 adduct of **4** and benzaldehyde ($\mathbf{9}_{anti}$ in Scheme 7), and the rate-determining step for the triple-aldehyde addition appears to be the third aldehyde addition.

The yields of type-**16** adducts were slightly improved when the first aldehyde was employed in 2.2 molar equivalents before addition of the second aldehyde (Scheme 9).



Scheme 8. Sequential aldehyde addition of **4** to benzaldehyde and *p*-anisaldehyde.



Scheme 9. Synthesis of **16**.

Conclusions

In summary, we have demonstrated that 1,2,3,4-tetraborylated 2-butenes, which is a new type of metalated allyl metal, undergo triple-aldehyde addition in a one-pot manner to give 2,3-bis(alkylidene)alkane-1,5-diols as single stereoisomers. The cascade reaction involves sequential conversion of four C–B bonds into two C–C bonds and one C=C bond with perfect stereocontrol in each step. Furthermore, one-pot preparation and triple addition of the tetraborylbutene reagent is also achieved. These results clearly illustrate the high potential and synthetic utility of designer tetrametalated compounds as reagents for cascade reactions.

Experimental Section

General

All manipulations of oxygen- and moisture-sensitive materials were conducted with standard Schlenk techniques under argon atmosphere. Melting points were determined using a Yanagimoto Micro melting-point apparatus and are uncorrected. ^{1}H NMR spectra were recorded on Varian Mercury 200 (200 MHz), 300 (300 MHz), and 400 (400 MHz) spectrometers with tetramethylsilane ($\delta=0$ ppm) or chloroform ($\delta=7.26$ ppm) as an internal standard. Splitting patterns are indicated as s = singlet, d = doublet, t = triplet, q = quartet, br s = broad singlet. ^{13}C NMR spectra were obtained on Varian Mercury 400 (100 MHz) and JEOL EX-270 (67.8 MHz) spectrometers with tetramethylsilane as an internal standard ($\delta=0$ ppm) or [D]chloroform ($\delta=77.0$ ppm). Owing to quadrupolar relaxation, carbon atoms with a boron substituent were not detected. ^{19}F NMR spectra were obtained on a Varian Mercury 200 (188 MHz) spectrometer with $CFCl_3$ as an internal standard ($\delta=0$ ppm). All chemical shifts are given in parts per million relative to the internal standard. IR spectra were recorded on a Shimadzu FTIR-8400 spectrometer. GC–MS analysis was performed on a JEOL JMS-700 spectrometer with electron ionization at 70 eV. Elemental analysis was carried out on a Yanako MT2 CHN Corder machine at the Elemental Analysis Center of Kyoto University. TLC analysis was performed with Merck Kieselgel 60 F254. Column chromatography was carried out with Wako gel C-200 or silica gel 60 (Kanto Chemical Co., Inc.). Bis(pinacolato)diboron was purchased from Boron Molecular Co., Inc.

Syntheses

4: A solution of **5** (31 mg, 0.10 mmol), **6** (25 mg, 0.10 mmol), and [Pt(PPh$_3$)$_4$] (3.7 mg, 3.0 μmol) in toluene (2 mL) was heated at 80 °C for 12 h. Workup and column chromatography on silica gel gave (*Z*)-1,2,3,4-tetrakis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)but-2-ene (**4**; 55 mg, 99 % yield) as a colorless solid. The *Z* stereochemistry of **4** was deduced from the stereochemical outcome in the Pt-catalyzed 1,4-diborylation of 1,3-dienes.[6b] $R_f=0.40$ (hexane/ethyl acetate = 2:1); ^{1}H NMR (200 MHz, $CDCl_3$): $\delta=1.20$ (s, 24H), 1.25 (s, 24H), 1.83 ppm (s, 4H); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta=19.8$ (br s), 24.7, 24.8, 82.8, 83.1, 126.0 ppm (br s); MS (EI): *m*/*z* (%) = 561 (10) $[M+1]^+$, 560 (11) $[M]^+$, 545 (5) $[M-Me]^+$, 460 (23), 360 (26), 83 (100); HRMS (FAB): *m*/*z* calcd for $C_{28}H_{52}B_4O_8$: 560.4034 $[M]^+$; found: 560.4034; elemental analysis: calcd (%) for $C_{28}H_{52}B_4O_8$: C 60.06, H 9.36; found: C 59.80, H 9.11.

Typical procedure for triple-aldehyde addition of **4**: A solution of **4** (20 mg, 0.037 mmol) and benzaldehyde (14 mg, 0.13 mmol) in toluene (1 mL) was heated at 100 °C for 12 h. The reaction mixture was diluted with ethyl acetate (5 mL) and aqueous KOH (0.1 M, 20 mL). The aqueous layer was extracted with ethyl acetate (2 × 20 mL). The combined organic layer was washed with saturated aqueous NaCl, dried over anhydrous magnesium sulfate, and concentrated in vacuo. The residue was purified by preparative TLC (hexane/ethyl acetate = 2:1) to give (1*S**,5*S**)-3-(*Z*)-benzylidene-2-methylidene-1,5-diphenylpentane-1,5-diol (**7a**; 11 mg, 86 % yield) as a colorless oil. $R_f=0.50$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}=3339$, 3061, 3026, 2928, 1603, 1493, 1452, 1337, 1201, 1053, 1020, 918, 756, 698 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): $\delta=1.23$ (br s, 2H), 2.53 (dd, $J=14.0$, 10.5 Hz, 1H), 2.64 (ddd, $J=14.0$, 3.0, 1.8 Hz, 1H), 4.97 (dd, $J=10.5$, 3.0 Hz, 1H), 5.04 (s, 1H), 5.20 (s, 1H), 5.30 (s, 1H), 6.56 (s, 1H), 7.26–7.49 ppm (m, 15H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta=51.4$, 70.6, 74.5, 117.4, 125.6, 127.0, 127.1, 127.1, 127.8, 128.2, 128.2, 128.6, 128.8, 129.9, 137.3, 138.0, 141.3, 143.8, 150.4 ppm; elemental analysis: calcd (%) for $C_{25}H_{24}O_2$: C 84.24, H 6.79; found: C 84.24, H 6.87.

7a′: A mixture of **7a** (23 mg, 0.065 mmol), 4-dimethylaminopyridine (1.0 mg, 6.5 μmol), acetic anhydride (1 mL), and pyridine (1 mL) was stirred at room temperature for 12 h. The reaction mixture was diluted with ethyl acetate (5 mL) and aqueous NH_4Cl (15 mL). The aqueous layer was extracted with ethyl acetate (2 × 5 mL). The combined organic layer was washed with saturated aqueous NaCl, dried over anhydrous magnesium sulfate, and concentrated in vacuo. The residue was purified by preparative TLC (hexane/ethyl acetate = 2:1) to give (1*S**,5*S**)-1,5-diacetoxy-3-(*Z*)-benzylidene-2-methylidene-1,5-diphenylpentane (**7a′**; 29 mg, > 99 % yield) as a colorless oil. $R_f=0.70$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}=3063$, 3032, 2930, 1742, 1493, 1454, 1371, 1232, 1024, 921, 756, 698 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): $\delta=2.02$ (s, 3H), 2.04 (s, 3H), 2.40 (dd, $J=14.4$, 3.9 Hz, 1H), 2.69 (dd, $J=14.4$, 9.3 Hz, 1H), 5.06 (s, 1H), 5.24 (s, 1H), 5.82 (dd, $J=9.3$, 3.9 Hz, 1H), 6.30 (s, 1H), 6.31 (s, 1H), 7.20–7.23 ppm (m, 15H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta=21.2$, 21.2, 45.3, 73.8, 75.9, 117.5, 126.3, 126.8, 127.5, 127.8, 127.9, 128.1, 128.2, 128.3, 128.5, 131.5, 135.8, 136.6, 138.0, 140.2, 145.9, 169.3, 169.9 ppm; MS (EI): *m*/*z* (%) = 442 (0.1) $[M+2]^+$, 441 (0.2) $[M+1]^+$, 440 (0.4) $[M]^+$, 320 (100); HRMS (EI): *m*/*z* calcd for $C_{28}H_{28}O_4$: 440.1988 $[M]^+$; found:

440.1989; elemental analysis: calcd (%) for $C_{29}H_{28}O_4$: C 79.07, H 6.41; found: C 79.21, H 6.54.

Oxidation of **7a**: A solution of **7a** (24 mg, 0.067 mmol), MnO_2 (0.13 g, 1.0 mmol), and CH_2Cl_2 (3 mL) was stirred at 40 °C for 3.5 h. The solution was diluted with ethyl acetate, filtered through a florisil pad, and concentrated in vacuo. The residue was purified by preparative TLC (hexane/ethyl acetate = 2:1) to give 3-(*Z*)-benzylidene-2-methylene-1,5-diphenyl-5-hydroxypentan-1-one (**12**; 20 mg, 84% yield) as a yellow oil. $R_f = 0.70$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3421$, 3026, 2925, 1651, 1597, 1490, 1447, 1028, 980, 752, 698, 665 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): $\delta = 1.26$ (br s, 1H), 2.73 (dd, $J = 13.8$, 10.0 Hz, 1H), 2.90 (ddd, $J = 13.8$, 3.4, 1.6 Hz, 1H), 4.85 (dd, $J = 10.0$, 3.4 Hz, 1H), 5.99 (s, 1H), 6.10 (s, 1H), 6.78 (s, 1H), 7.03–8.10 ppm (m, 15H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta = 51.1$, 71.0, 125.6, 127.0, 127.1, 128.0, 128.0, 128.2, 128.6, 129.3, 129.8, 132.6, 133.1, 136.2, 136.3, 137.0, 143.6, 147.4, 197.6 ppm; elemental analysis: calcd (%) for $C_{25}H_{22}O_2$: C 84.72, H 6.26; found: C 84.49, H 6.33.

Reduction of **12**: A mixture of **12** (9.1 mg, 0.026 mmol), $NaBH_4$ (0.23 mg, 0.15 mmol), $CeCl_3{\cdot}7H_2O$ (9.5 mg, 0.026 mmol), and methanol (1 mL) was stirred at room temperature for 26 h before the reaction was quenched with water (20 mL). The aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined organic layer was washed with saturated aqueous NaCl, dried over anhydrous magnesium sulfate, and concentrated in vacuo. The residue was purified by preparative TLC to give a 1:1 diastereomeric mixture of **7a** (8.5 mg, 93% yield) as a colorless oil. As the *syn* and *anti* diastereomers of **7a** could not be separated, only the assignable signals of the *anti* isomer are shown. ^1H NMR (200 MHz, $CDCl_3$): $\delta = 4.41$ (dd, $J = 10.0$, 3.4 Hz, 1H), 5.24 (s, 1H), 5.28 (s, 1H), 5.55 (s, 1H), 6.55 ppm (s, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta = 50.7$, 72.4, 74.9, 115.2 ppm.

Cyclization of **7a**: Butyllithium (1.60 M in hexane, 70 μL, 0.11 mmol) was added to a solution of **7a** (17 mg, 0.049 mmol) in THF (2 mL) at 0 °C. The solution was stirred at 0 °C for 20 min and cooled to −78 °C before addition of methanesulfonyl chloride (7.4 mg, 0.054 mmol). The resulting solution was allowed to warm to room temperature before the reaction was quenched with saturated aqueous NH_4Cl (20 mL) at 0 °C. The aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined organic layer was washed with aqueous NaCl, dried over anhydrous magnesium sulfate, and concentrated in vacuo. The residue was purified by preparative TLC (hexane/ethyl acetate = 10:1) to give (2*R**,4*R**)-4-(*Z*)-benzylidene-3-methylidene-2,6-diphenyl-4-pyran (**13**; 12 mg, 75% yield) as a colorless oil. $R_f = 0.50$ (hexane/ethyl acetate = 10:1); IR (neat): $\tilde{\nu} =$ 3060, 3030, 2927, 1724, 1599, 1495, 1452, 1265, 1067, 1026, 920, 740, 698 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.70$–2.80 (m, 2H), 4.39 (s, 1H), 4.88 (dd, $J = 10.0$, 4.0 Hz, 1H), 4.95 (s, 1H), 5.29 (s, 1H), 6.42 (s, 1H), 7.16–7.50 ppm (m, 15H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 47.1$, 80.5, 83.1, 115.4, 125.4, 125.9, 126.5, 127.6, 127.7, 127.8, 128.1, 128.4, 128.9, 137.0, 138.5, 139.1, 141.9, 145.8 ppm; elemental analysis: calcd (%) for $C_{25}H_{22}O$: C 88.72, H 6.55; found: C 88.43, H 6.65.

14: (1*S**,5*S**)-3-(*E*)-Benzylidene-2-methylidene-1,5-diphenylpentane-1,5-diol, 52% yield, colorless oil. $R_f = 0.25$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3335$, 3026, 2926, 2855, 1647, 1602, 1491, 1450, 1026, 914, 758, 698, 665 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 1.56$ (br s, 2H), 2.73 (ddd, $J = 14.4$, 4.0, 1.2 Hz, 1H), 2.99 (dd, $J = 14.4$, 9.6 Hz, 1H), 4.89 (dd, $J = 9.6$, 4.0 Hz, 1H), 5.17 (s, 1H), 5.38 (s, 1H), 5.65 (s, 1H), 6.77 (s, 1H), 7.21–7.48 ppm (m, 15H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 39.9$, 72.5, 75.6, 115.0, 125.6, 126.7, 126.8, 127.4, 127.7, 128.0, 128.3, 128.3, 128.8, 131.3, 131.3, 137.1, 137.6, 141.8, 143.8, 152.0 ppm. As compound **14** was unstable for EI MS and elementary analysis, HRMS was effected after conversion of **14** into its diacetate (1*S**,5*S**)-1,5-diacetoxy-3-(*E*)-benzylidene-2-methylidene-1,5-diphenylpentane (**14′**): 83% yield, colorless oil. $R_f = 0.55$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3032$, 2932, 1738, 1603, 1493, 1454, 1371, 1234, 1178, 1022, 921, 802, 756, 700, 665 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.01$ (s, 3H), 2.05 (s, 3H), 2.75 (dd, $J = 14.0$, 6.4 Hz, 1H), 3.03 (dd, $J = 14.0$, 8.0 Hz, 1H), 5.43 (s, 1H), 5.48 (s, 1H), 5.86 (dd, $J = 8.0$, 6.4 Hz, 1H), 6.63 (s, 1H), 6.70 (s, 1H), 6.91–7.06 (m, 4H), 7.17–7.44 ppm (m, 11H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 21.3$, 21.4, 35.7, 74.5, 75.6, 115.0, 126.3, 126.6, 127.6, 127.7, 127.9, 128.1, 128.1, 128.3, 128.5, 132.1, 135.5, 136.9, 138.2, 139.8, 147.3, 169.6, 169.8 ppm; MS (EI): *m*/*z* (%) = 440 (0.3) $[M]^+$, 320 (100); HRMS (EI): *m*/*z* calcd for $C_{29}H_{28}O_4$: 440.1988 $[M]^+$; found: 440.1984.

7b: (1*S**,5*S**)-1,5-Bis(4-methoxyphenyl)-3-(*Z*)-(4-methoxyphenylmethylidene)-2-methylidenepentane-1,5-diol, 80% yield, colorless oil. $R_f = 0.30$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3400$, 2930, 2840, 2350, 1608, 1508, 1302, 1250, 1175, 1034, 665 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): $\delta =$ 1.26 (br s, 2H), 2.49 (dd, $J = 9.6$, 6.8 Hz, 1H), 2.60 (ddd, $J = 9.6$, 2.2, 1.0 Hz, 1H), 3.81 (s, 3H), 3.81 (s, 3H), 3.83 (s, 3H), 4.89 (dd, $J = 6.8$, 2.2 Hz, 1H), 5.10 (s, 1H), 5.20 (s, 1H), 5.26 (s, 1H), 6.46 (s, 1H), 6.84–6.90 (m, 6H), 7.22 (d, $J = 5.8$ Hz, 2H), 7.27 (d, $J = 5.8$ Hz, 2H), 7.40 ppm (d, $J = 5.8$ Hz, 2H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta = 55.3$, 70.2, 74.1, 113.6, 113.6, 113.7, 116.6, 126.8, 128.3, 129.2, 129.9, 133.5, 136.1, 136.2, 136.3, 150.8, 158.5, 158.6, 159.9 ppm; elemental analysis: calcd (%) for $C_{28}H_{30}O_5$: C 75.31, H 6.77; found: C 75.16, H 6.77.

7c: (1*S**,5*S**)-1,5-Bis(biphenyl-4-yl)-2-methylidene-3-(*Z*)-(biphenyl-4-yl)-methylidene-pentane-1,5-diol, 86% yield, colorless solid. $R_f = 0.45$ (hexane/ethyl acetate = 2:1); m.p.: 170.7 °C (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3333$, 3053, 3026, 2912, 2895, 1599, 1485, 1406, 1269, 1028, 1006, 837, 763, 733, 694 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): $\delta = 1.26$ (br s, 2H), 2.63 (dd, $J = 14.4$, 9.6 Hz, 1H), 2.79 (dm, $J = 14.4$ Hz, 1H), 5.06 (dd, $J = 9.6$, 2.6 Hz, 1H), 5.20 (s, 1H), 5.38 (s, 1H), 5.39 (s, 1H), 6.63 (s, 1H), 7.35–7.65 ppm (m, 27H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta = 51.4$, 70.5, 76.5, 117.5, 126.0, 126.8, 126.9, 127.0, 127.0, 127.0, 127.1, 127.3, 127.3, 127.3, 127.5, 128.6, 128.7, 128.7, 128.7, 129.1, 129.6, 136.2, 138.1, 139.7, 140.0, 140.3, 140.5, 140.6, 140.7, 140.8, 142.9, 150.3 ppm. As compound **7c** was not stable for EI MS and elementary analysis, HRMS was effected after conversion of **7c** into its diacetate (1*S**,5*S**)-1,5-diacetoxy-1,5-bis-(biphenyl-4-yl)-3-(*Z*)-(biphenyl-4-yl)methylidene-2-methylidenepentane (**7c′**): 90% yield, colorless solid. $R_f = 0.40$ (hexane/ethyl acetate = 4:1); m.p.: 162.2 °C (hexane/ethyl acetate = 2:1); IR (KBr): $\tilde{\nu} = 3028$, 2359, 2341, 1734, 1487, 1731, 1236, 1031, 999, 937, 766, 756, 733, 690 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.00$ (s, 3H), 2.01 (s, 3H), 2.46 (dd, $J =$ 14.4, 4.8 Hz, 1H), 2.72 (dd, $J = 14.4$, 9.2 Hz, 1H), 5.10 (s, 1H), 5.32 (s, 1H), 5.87 (dd, $J = 9.2$, 4.8 Hz, 1H), 6.32 (s, 1H), 6.35 (s, 1H), 7.18–7.51 ppm (m, 27H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 21.2$, 21.2, 45.3, 73.6, 75.9, 117.7, 126.6, 126.9, 127.1, 127.1, 127.2, 127.3, 127.4, 127.4, 128.0, 128.7, 128.7, 129.1, 131.3, 135.7, 135.9, 137.0, 139.3, 139.6, 140.6, 140.6, 140.9, 141.2, 145.9, 169.6, 170.2 ppm; MS (FAB): *m*/*z* (%) = 669 (0.5) $[M+1]^+$, 668 (1) $[M]^+$, 154 (100); HRMS (FAB): *m*/*z* calcd for $C_{47}H_{40}O_4$: 668.2927 $[M]^+$; found: 668.2932.

7d: (1*S**,5*S**)-2-Methylidene-1,5-bis(4-trifluoromethylphenyl)-3-(*Z*)-(4-trifluoromethylphenyl)methylidenepentane-1,5-diol, 63% yield, colorless oil. $R_f = 0.50$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3269$, 2929, 2856, 1620, 1413, 1325, 1165, 1124, 1069, 1016, 829 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$): $\delta = 1.26$ (br s, 2H), 2.57 (dd, $J = 14.3$, 10.3 Hz, 1H), 2.76 (dm, $J =$ 14.3 Hz, 1H), 4.99–5.00 (m, 2H), 5.21 (s, 1H), 5.35 (s, 1H), 6.58 (s, 1H), 7.32–7.62 ppm (m, 12H); ^{13}C NMR (67.8 MHz, $CDCl_3$): $\delta = 51.0$, 70.3, 74.3, 119.0, 121.2 (q, $J = 270.0$ Hz), 122.5, 122.6, 125.1 (q, $J = 3.8$ Hz, 2C), 125.3 (q, $J = 3.8$ Hz), 126.9 (q, $J = 275.0$ Hz), 127.7 (q, $J = 272.0$ Hz), 128.7, 129.1, 129.2 (q, $J = 32.8$ Hz), 129.5 (q, $J = 32.1$ Hz), 130.2 (q, $J = 30.0$ Hz), 139.4, 140.4, 144.6, 147.4, 148.9 ppm; ^{19}F NMR (188 MHz, $CDCl_3$): $\delta =$ −62.9, −63.0, −63.0 ppm; elemental analysis: calcd (%) for $C_{28}H_{21}F_9O_2$: C 60.01, H 3.78; found: C 60.01, H 4.00.

7e: (1*S**,5*S**)-2-Methylidene-1,5-di(naphth-2-yl)-3-(*Z*)-(naphth-2-yl)-methylidenepentane-1,5-diol, 63% yield, colorless solid. $R_f = 0.45$ (hexane/ethyl acetate = 2:1); m.p.: 162.2 °C (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3335$, 3053, 2931, 2358, 2329, 1717, 1699, 1684, 1506, 1361, 1049, 1010, 858, 820, 749, 669, 476 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): $\delta =$ 1.25 (br s, 2H), 2.74 (dd, $J = 14.4$, 10.8 Hz, 1H), 2.90 (d, $J = 14.4$ Hz, 1H), 3.71 (s, 1H), 5.14 (s, 1H), 5.23 (d, $J = 10.8$ Hz, 1H), 5.45 (s, 1H), 6.78 (s, 1H), 7.42–7.93 ppm (m, 21H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 51.6$, 70.7, 74.8, 118.3, 123.9, 124.0, 124.9, 125.5, 125.9, 126.1, 126.2, 126.8, 127.5, 127.6, 127.7, 127.8, 127.8, 127.9, 130.0, 132.4, 132.6, 133.0, 133.2, 134.8, 138.5, 138.5, 141.2, 150.2 ppm. As compound **7e** was not stable for EI MS and elementary analysis, HRMS was effected after conversion of **7e** into its diacetate (1*S**,5*S**)-1,5-diacetoxy-2-methylidene-1,5-di(naphth-2-yl)-3-(*Z*)-(naphth-2-yl)-methylidenepentane (**7e′**): 84% yield, colorless solid. $R_f = 0.40$ (hexane/ethyl acetate = 4:1); m.p.: 95.2 °C (hexane/ethyl

acetate = 4:1); IR (KBr): $\tilde{\nu}$ = 2922, 2359, 2341, 1734, 1369, 1234, 1028, 854, 737, 670 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.06 (s, 6H), 2.64 (dd, J = 14.4, 4.8 Hz, 1H), 2.88 (dd, J = 14.4, 9.2 Hz, 1H), 5.18 (s, 1H), 5.38 (s, 1H), 6.07 (dd, J = 8.8, 4.8 Hz, 1H), 6.51 (s, 1H), 6.57 (s, 1H), 7.37–7.82 ppm (m, 21H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.2, 24.6, 45.2, 74.0, 76.2, 118.1, 124.2, 125.1, 125.6, 125.8, 125.9, 126.1, 126.2, 126.3, 126.7, 127.0, 127.3, 127.5, 127.7, 127.9, 128.0, 128.1, 128.2, 131.8, 132.4, 133.0, 133.2, 134.2, 135.3, 136.3, 137.6, 145.8 ppm; MS (FAB): m/z (%) = 592 (0.3) $[M+2]^+$, 591 (1) $[M+1]^+$, 590 (2) $[M]^+$, 154 (100); HRMS (FAB): m/z calcd for $C_{41}H_{34}O_4$: 590.2457 $[M]^+$; found: 590.2455.

7f: (1*S**,5*S**)-1,5-Bis(3-methoxyphenyl)-3-(*Z*)-(3-methoxyphenyl)methylidene-2-methylidenepentane-1,5-diol, 69% yield, colorless oil. R_f = 0.50 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3385, 2936, 2835, 1601, 1585, 1489, 1459, 1436, 1317, 1263, 1043, 910, 874, 781, 733, 698 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.23 (br s, 2H), 2.53 (dd, J = 14.0, 10.4 Hz, 1H), 2.70 (ddd, J = 14.0, 2.8, 2.0 Hz, 1H), 3.83 (s, 3H), 3.86 (s, 6H), 4.95 (dd, J = 10.4, 2.8 Hz, 1H), 5.09 (s, 1H), 5.20 (s, 1H), 5.31 (s, 1H), 6.53 (s, 1H), 6.78–7.38 ppm (m, 12H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 51.3, 55.2, 55.2, 55.3, 70.5, 74.6, 111.0, 112.5, 112.8, 113.4, 114.0, 117.3, 117.9, 119.3, 121.3, 129.1, 129.2, 129.2, 129.7, 138.3, 138.6, 142.9, 145.6, 150.1, 159.3, 159.5, 159.6 ppm; elemental analysis: calcd (%) for $C_{28}H_{30}O_5$: C 75.31, H 6.77; found: C 75.24, H 6.86.

7g: (1*S**,5*S**)-1,5-Bis(2-methoxyphenyl)-3-(*Z*)-(2-methoxyphenyl)methylidene-2-methylidenepentane-1,5-diol, 82% yield, colorless oil. R_f = 0.27 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3385, 2932, 2835, 1600, 1491, 1458, 1437, 1244, 1115, 1028, 912, 752 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.53 (dd, J = 14.0, 10.4 Hz, 1H), 3.02 (ddd, J = 14.0, 2.4, 1.8 Hz, 1H), 3.48 (br s, 1H), 3.55 (br s, 1H), 3.79 (s, 3H), 3.86 (s, 6H), 4.78 (s, 1H), 5.12 (s, 1H), 5.28 (dd, J = 10.4, 2.4 Hz, 1H), 5.50 (s, 1H), 6.66 (s, 1H), 6.86–7.58 ppm (m, 12H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 48.0, 55.3, 55.3, 55.5, 66.6, 71.4, 110.0, 110.4, 110.5, 116.0, 120.0, 120.6, 120.7, 125.2, 126.2, 126.6, 127.7, 128.0, 128.4, 128.5, 129.4, 129.9, 132.2, 138.7, 148.9, 155.7, 156.5, 156.8 ppm. As compound **7g** was unstable for EI MS and elementary analysis, HRMS was effected after conversion of **7g** into its diacetate (1*S**,5*S**)-1,5-diacetoxy-1,5-bis(2-methoxyphenyl)-3-(*Z*)-(2-methoxyphenyl)methylidene-2-methylidenepentane (**7g′**): 79% yield, colorless solid. R_f = 0.25 (hexane/ethyl acetate = 4:1); m.p.: 112.5 °C (hexane/ethyl acetate = 2:1); IR (KBr): $\tilde{\nu}$ = 2954, 2837, 2359, 2341, 1737, 1600, 1498, 1465, 1369, 1286, 1231, 1026, 923, 744 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.03 (s, 3H), 2.09 (s, 3H), 2.60 (dd, J = 14.4, 10.4 Hz, 1H), 2.95 (d, J = 14.4 Hz, 1H), 3.79 (s, 3H), 3.81 (s, 3H), 3.92 (s, 3H), 4.70 (s, 1H), 4.94 (s, 1H), 6.37 (dd, J = 10.4, 3.2 Hz, 1H), 6.55 (s, 1H), 6.78–7.50 ppm (m, 13H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 20.9, 21.0, 43.3, 55.1, 55.2, 55.3, 69.0, 70.2, 110.1, 110.3, 110.3, 118.9, 119.8, 120.3, 125.6, 126.2, 126.7, 127.2, 127.4, 127.7, 128.3, 128.8, 129.7, 130.1, 144.7, 156.0, 156.8, 157.1, 169.6, 170.0 ppm; MS (FAB): m/z (%) = 532 (0.2) $[M+2]^+$, 531 (0.6) $[M+1]^+$, 530 (0.4) $[M]^+$, 154 (100); HRMS (FAB): m/z calcd for $C_{32}H_{34}O_7$: 530.2305 $[M]^+$; found: 530.2300.

7h: (1*S**,5*S**)-1,5-Bis(3,5-dimethoxyphenyl)-(*Z*)-3-(3,5-dimethoxyphenyl)methylidene-2-methylidenepentane-1,5-diol, 57% yield, colorless oil. R_f = 0.15 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3414, 2959, 2939, 2837, 1599, 1462, 1429, 1346, 1313, 1294, 1205, 1155, 1062, 925, 837, 736, 702 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.20 (br s, 2H), 2.52 (dd, J = 14.0, 10.8 Hz, 1H), 2.68 (dd, J = 14.0, 2.8 Hz, 1H), 3.76 (s, 12H), 3.79 (s, 6H), 4.89 (dd, J = 10.8, 2.8 Hz, 1H), 5.13 (s, 1H), 5.17 (s, 1H), 5.29 (s, 1H), 6.35–6.64 ppm (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.8, 51.2, 55.2, 55.3, 70.4, 74.6, 75.0, 99.2, 99.3, 99.9, 103.4, 104.9, 106.8, 117.5, 129.7, 138.7, 138.7, 139.2, 143.8, 146.6, 149.9, 160.5, 160.7, 160.7 ppm; elemental analysis: calcd (%) for $C_{31}H_{36}O_8$: C 69.39, H 6.76; found: C 69.16, H 6.78.

7i: (3*S**,7*S**)-4-Methylidene-1,9-diphenyl-5-(*Z*)-(3-phenylpropylidene)nonane-3,7-diol, 83% yield, colorless oil. R_f = 0.30 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3379, 3024, 2922, 2856, 1602, 1495, 1454, 1045, 1030, 912, 748, 698 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.57–2.00 (m, 6H), 2.12 (dd, J = 14.0, 8.8 Hz, 1H), 2.35–2.40 (m, 3H), 2.59–2.69 (m, 4H), 2.72–2.81 (m, 2H), 3.57–3.64 (m, 1H), 4.08 (dd, J = 8.8, 4.0 Hz, 1H), 4.58 (s, 1H), 5.19 (s, 1H), 5.42 (t, J = 6.8 Hz, 1H), 7.09–7.30 ppm (m, 15H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 31.2, 32.1, 32.2, 36.2, 37.0, 37.6, 38.4, 40.9, 45.4, 69.3, 73.2, 113.6, 125.7, 125.8, 125.9, 128.2, 128.3, 128.4, 128.4, 130.9, 137.4, 141.5, 141.9, 141.9, 150.1 ppm; elemental analysis: calcd (%) for $C_{31}H_{36}O_2$: C 84.50, H 8.24; found: C 84.56, H 8.31.

7j: (3*S**,7*S**)-4-Methylidene-5-(*Z*)-propylidenenonane-3,7-diol, 71% yield, colorless oil. R_f = 0.26 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3320, 2962, 2931, 2855, 1718, 1701, 1647, 1541, 1508, 1490, 1109, 974, 910 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.91–1.03 (m, 9H), 1.24–1.74 (m, 5H), 2.01–2.20 (m, 4H), 2.42 (ddd, J = 14.2, 4.6, 1.6 Hz, 1H), 3.53–3.66 (m, 1H), 4.11 (dd, J = 7.4, 4.6 Hz, 1H), 4.86 (d, J = 1.6 Hz, 1H), 5.40 ppm (t, J = 7.4 Hz, 1H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 10.1, 10.3, 14.8, 22.5, 28.3, 29.7, 44.9, 71.5, 74.7, 113.4, 133.5, 136.4, 150.4 ppm; elemental analysis: calcd (%) for $C_{13}H_{24}O_2$: C 73.54, H 11.39; found: C 73.31, H 11.57.

7k: (2*S**,6*S**)-1,7-Dibenzyloxy-4-(*Z*)-(2-benzyloxyethylidene)-3-methylideneheptane-2,6-diol, 73% yield, colorless oil. R_f = 0.28 (hexane/ethyl acetate = 1:1); IR (neat): $\tilde{\nu}$ = 3398, 3030, 2925, 2858, 1452, 1364, 1271, 1072, 1028, 916, 736, 698 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.37 (d, J = 6.4 Hz, 1H), 2.58 (s, 1H), 2.95 (s, 1H), 3.35 (dd, J = 9.2, 6.8 Hz, 1H), 3.40 (dd, J = 9.6, 7.2 Hz, 1H), 3.45 (dd, J = 9.6, 3.6 Hz, 1H), 3.47 (dd, J = 9.2, 3.6 Hz, 1H), 3.89–3.96 (m, 1H), 3.98 (dd, J = 6.8, 2.4 Hz, 2H), 4.43 (s, 2H), 4.52 (s, 2H), 4.53 (s, 2H), 4.53 (s, 2H), 4.90 (s, 1H), 5.37 (s, 1H), 5.64 (t, J = 6.4 Hz, 1H), 7.26–7.36 ppm (m, 15H); ^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 40.8, 67.2, 68.8, 71.3, 72.8, 73.0, 73.3, 73.4, 73.5, 115.7, 127.5, 127.6, 127.6, 127.7, 128.3, 128.3, 128.3, 137.7, 138.1, 140.3, 145.8 ppm; elemental analysis: calcd (%) for $C_{31}H_{36}O_5$: C 76.20, H 7.43; found: C 76.20, H 7.38.

One-pot preparation/triple-aldehyde addition of **4**: A solution of **5** (0.10 g, 0.33 mmol), **6** (0.10 g, 0.40 mmol), benzaldehyde (0.12 g, 1.1 mmol), and $[Pt(PPh_3)_4]$ (12 mg, 9.8 μmol) in toluene (8 mL) was stirred at 100 °C for 11 h. The mixture was diluted with ethyl acetate (20 mL) and aqueous KOH (0.1 M, 20 mL). The aqueous layer was extracted with ethyl acetate (3 × 15 mL). The combined organic layer was washed with saturated aqueous NaCl (20 mL), dried over anhydrous magnesium sulfate, and concentrated in vacuo. The residue was purified by column chromatography on silica gel (hexane/ethyl acetate = 10:1 → 2:1) to give **7a** (85 mg, 73% yield) as a colorless oil.

16a: (1*S**,5*S**)-3-(*Z*)-(4-Methoxyphenyl)methylidene-2-methylidene-1,5-diphenylpentane-1,5-diol, 51% yield, colorless oil. R_f = 0.40 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3342, 3007, 2909, 2835, 2362, 1604, 1508, 1452, 1438, 1298, 1252, 1217, 1177, 1033, 918, 835, 756, 700, 667 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.67 (br s, 2H), 2.51 (dd, J = 14.4, 10.8 Hz, 1H), 2.65 (dm, J = 14.4 Hz, 1H), 3.84 (s, 3H), 4.95 (dd, J = 10.8, 2.8 Hz, 1H), 5.08 (s, 1H), 5.26 (s, 1H), 5.30 (s, 1H), 6.49 (s, 1H), 6.88 (d, J = 8.8 Hz, 2H), 7.25–7.43 ppm (m, 12H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 51.4, 55.3, 70.6, 74.5, 113.6, 117.0, 125.5, 127.0, 127.1, 127.8, 128.1, 129.4, 129.8, 129.8, 136.0, 141.3, 143.8, 150.5, 158.5 ppm. As compound **16a** was unstable for EI MS and elementary analysis, HRMS was effected after conversion of **16a** into its diacetate (1*S**,5*S**)-1,5-diacetoxy-3-(*Z*)-(4-methoxyphenyl)methylidene-2-methylidene-1,5-diphenylpentane-1,5-diol (**16a′**): 51% yield, colorless oil. R_f = 0.45 (hexane/ethyl acetate = 2:1); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.99 (s, 3H), 1.99 (s, 3H), 2.33 (dd, J = 14.4, 4.8 Hz, 1H), 2.60 (d, J = 14.4, 9.2 Hz, 1H), 3.76 (s, 3H), 5.02 (s, 1H), 5.22 (s, 1H), 5.80 (dd, J = 9.2, 4.8 Hz, 1H), 6.20 (s, 1H), 6.27 (s, 1H), 6.73 (d, J = 8.8 Hz, 2H), 7.18–7.29 ppm (m, 12H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.2, 21.3, 45.5, 55.2, 73.8, 75.9, 113.3, 117.1, 126.3, 127.4, 127.7, 128.1, 128.2, 128.2, 129.2, 129.7, 130.9, 133.6, 138.0, 140.3, 146.1, 158.4, 169.3, 169.9 ppm; MS (EI): m/z (%) = 470 (0.2) $[M]^+$, 91 (100); HRMS: m/z calcd for $C_{30}H_{30}O_5$: 470.2093 $[M]^+$; found: 470.2098.

16b: (3*S**,7*S**)-5-(*Z*)-Benzylidene-4-methylidene-1,9-diphenylnonane-3,7-diol, 50% yield, colorless oil. R_f = 0.50 (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu}$ = 3252, 3024, 2918, 2853, 2340, 1603, 1495, 1454, 1423, 1325, 1078, 1032, 903, 833, 742, 698, 557 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.70–1.99 (m, 4H), 2.34–2.88 (m, 6H), 3.84–3.90 (m, 1H), 4.05–4.08 (m, 1H), 5.17 (s, 1H), 5.41 (s, 1H), 6.44 (s, 1H), 7.10–7.34 ppm (m, 15H); ^{13}C NMR (100 MHz, $CDCl_3$): δ = 32.4, 36.7, 38.8, 48.6, 68.2, 71.4, 114.3, 125.7, 125.7, 126.9, 128.0, 128.2, 128.3, 128.3, 128.4, 129.3, 137.0, 138.7, 141.6, 142.0, 150.8 ppm. As compound **16b** was unstable for EI MS and elementary analysis, HRMS was effected after conversion of **16b** into its

diacetate (3*S**,7*S**)-3,7-diacetoxy-5-(*Z*)-benzylidene-4-methylidenenonane (**16b′**): 63% yield, colorless oil. $R_f = 0.60$ (hexane/ethyl acetate = 2:1); IR (neat): $\tilde{\nu} = 3026, 2925, 2858, 1736, 1602, 1497, 1454, 1371, 1238, 1030, 748, 698, 665\ cm^{-1}$; ^1H NMR (400 MHz, $CDCl_3$): $\delta = 1.96$ (s, 3H), 2.01 (s, 3H), 2.18–2.05 (m, 10H), 5.09 (s, 1H), 5.29 (s, 1H), 5.40–5.43 (m, 1H), 5.48–5.50 (m, 1H), 6.35 (s, 1H), 7.06–7.36 ppm (m, 15H); ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 21.1, 21.3, 31.7, 31.9, 34.6, 35.9, 43.1, 71.8, 73.6, 116.8, 125.8, 126.8, 127.9, 128.2, 128.2, 128.3, 128.7, 130.7, 136.4, 141.1, 141.3, 145.2, 169.8, 170.4$ ppm; MS (EI): *m*/*z* (%) = 496 (0.1) $[M]^+$, 285 (100); HRMS (EI): *m*/*z* calcd for $C_{33}H_{36}O_4$: 496.2614 $[M]^+$; found: 496.2632.

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