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# Synthesis of cordiaquinone J and K via *B*-alkyl Suzuki–Miyaura coupling as a key step and determination of the absolute configuration of natural products

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**Abstract**—A versatile methodology for the synthesis of various terpenoids via *B*-alkyl Suzuki–Miyaura coupling as a key step is established. Synthesis of cordiaquinone J and K, new antifungal and larvicidal meroterpenoids, was achieved by using this methodology. The absolute configurations of cordiaquinone J and K were confirmed by the synthesis.


## 1. Introduction

Cordiaquinones are antifungal and larvicidal meroterpenoids isolated from Panamanian plants such as *Cordia linnaei*. In 1990, Messana and co-workers reported the isolation and structures of cordiaquinones A (**1**) and B (**2**) (Fig. 1).[1] After their identification of cordiaquinones from the plant, several cordiaquinones have been isolated.[2,3] In 2000, Hostettmann and co-workers reported the structures of cordiaquinones J (**3**) and K (**4**) isolated from *C. curassavica* (Fig. 1).[4] These compounds exhibit antifungal activities against phytopathogenic fungus such as *Cladosporium cucumerinum* and larvicidal activity against the larvae of the yellow fever-transmitting mosquito *Aedes aegypti*. The structures of cordiaquinone J and K were established on the basis of HRMS, UV and 1D and 2D NMR spectra. In connection with our synthetic studies of biologically active natural terpenoids,[5] we became interested in clarifying the absolute configuration of cordiaquinones. The synthesis and absolute configuration of cordiaquinone B were reported by

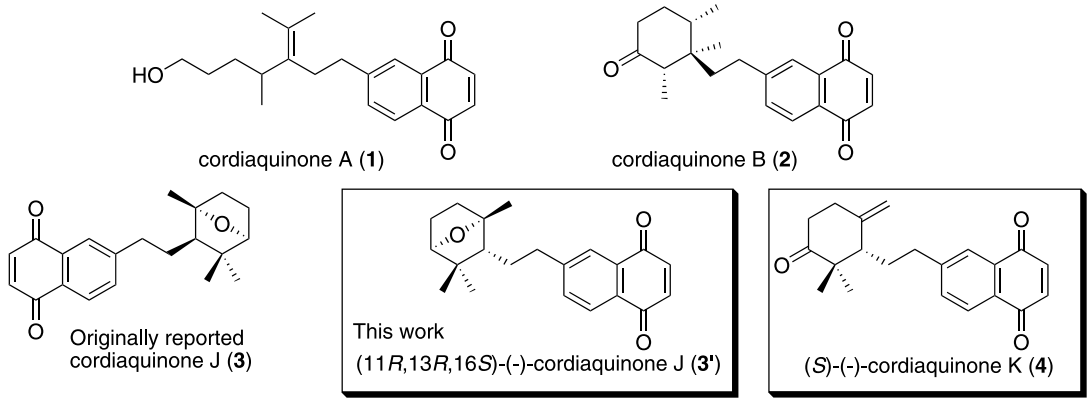


**Figure 1.** Structures of cordiaquinones.

*Keywords*: Synthesis; *B*-Alkyl Suzuki–Miyaura coupling; Cordiaquinones; Absolute configuration.
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Asaoka and his co-workers.[6] In previous communications, we reported the synthesis of (*R*)-(+)-cordiaquinone K employing one-pot *B*-alkyl Suzuki–Miyaura coupling as a key step and the determination of the absolute configuration of the natural product.[7] Although the absolute configuration of cordiaquinone K was determined to be *S* as shown in Figure 1, the absolute configuration of cordiaquinone J remained unknown. In recent structural studies of natural products, NOE studies are a powerful tool, especially for relative stereochemistry determination. However, Hostettmann provided no clear information on the relative stereochemistry of cordiaquinone J, including NOE experiment.[4] To clarify the stereochemistry, we decided to synthesize cordiaquinone J. This paper describes details of the synthesis of (*R*)-(+)-cordiaquinone K, (11*R*,13*S*,16*R*)- and (11*S*,13*R*,16*S*)-cordiaquinone J employing one-pot *B*-alkyl Suzuki–Miyaura coupling[8] as a key step. This paper also describes the determination of the relative and absolute configuration of the natural products.

## 2. Results and discussion

Our synthetic plans for the synthesis of cordiaquinone J and K are shown in Scheme 1. Appropriate transformations of the oxygen functionality at C-13 led to hydroxyolefines **A** and **B**, respectively. Disconnection between C-6 and C-9 gave γ-cyclohomogeranyl units **D** and **E**, respectively, and naphtoquinone derivative **C**. We planned to apply *B*-alkyl Suzuki–Miyaura coupling reaction to connect these units. This methodology would be useful for not only the synthesis of cordiaquinones but also various terpenoids such as ambrein,[9] luffarin W,[10] penlanpallescensin.[11] (Fig. 2), because these compounds have a common structural feature with cordiaquinones, namely, a γ-cyclohomogeranyl unit connecting with an aryl or a vinyl unit. Optically active γ-cyclohomogeranyl units could be derived from known hydroxyketone **F**, [12] obtained by yeast-mediated asymmetric reduction of the corresponding diketone. Naphtoquinone derivative **C** would be synthesized from known 6-bromonaphtoquinone.[13]

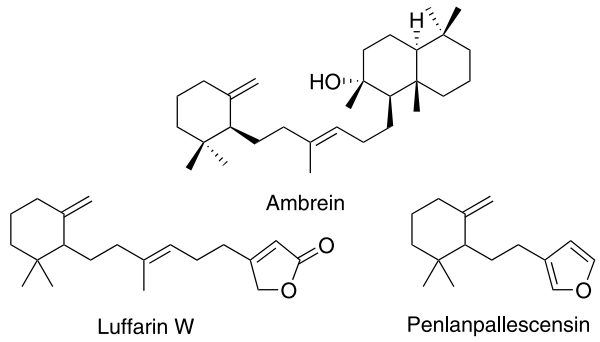
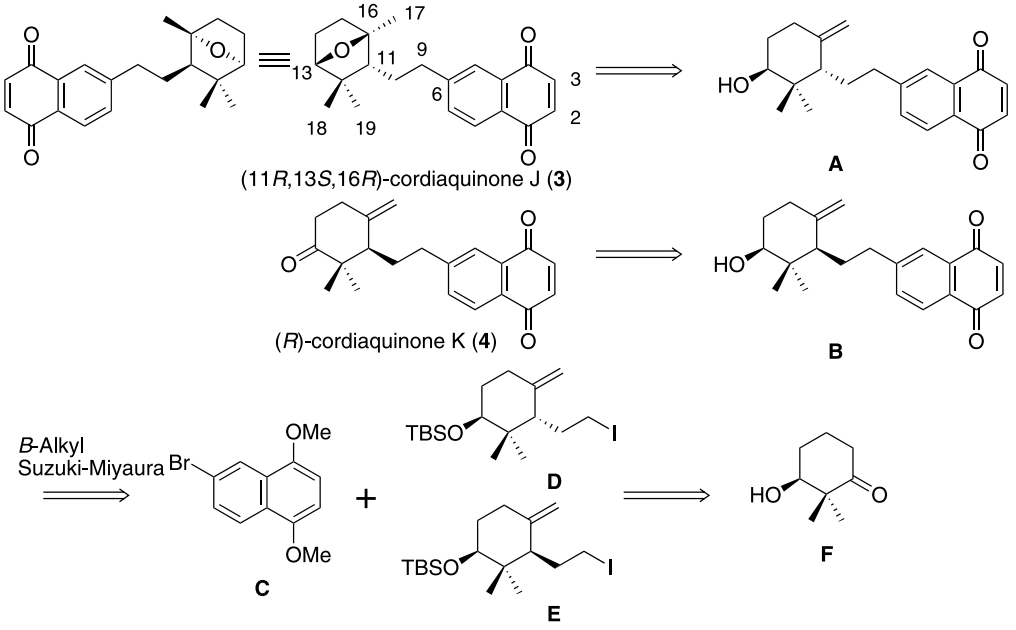
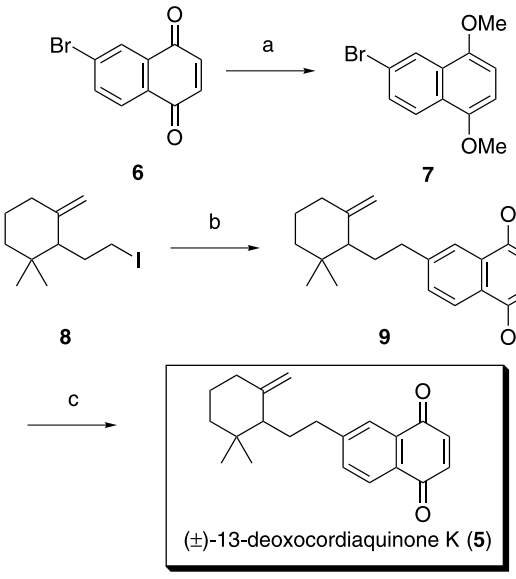



**Figure 2.** Structures of natural products with related structure of cordiaquinones.

As our target, we first chose (±)-13-deoxocordiaquinone K (**5**), since there was an urgent need to establish the appropriate conditions of the coupling reaction. Scheme 2 summarizes our synthesis of (±)-13-deoxocordiaquinone K (**5**). 6-Bromonaphtoquinone[13] (**6**) and (±)-γ-cyclohomogeranyl iodide[5a,14] (**8**) were selected as the starting materials. 6-Bromonaphtoquinone (**6**) was first hydrogenated with $PtO_2$ followed by methylation of the resulting hydroxyl groups to give **7**. (±)-γ-Cyclohomogeranyl iodide (**8**) was derived from the corresponding alcohol.[15] To connect the γ-cyclohomogeranyl unit (**8**) and the naphtoquinone derivative (**7**), we examined one-pot *B*-alkyl Suzuki–Miyaura coupling reaction. As a preliminary experiment for the coupling of **8** with **7**, the conditions reported by Marshall and Johns[16] {$PdCl_2$(dppf) as a catalyst} were examined to give the desired product (**9**) in only 10% yield based on **8**. Then we examined various conditions. Table 1 summarizes reaction conditions and yields of **9**. Although $PdCl_2$(dppf) was not an effective catalyst (entries 1–3), $Pd(PPh_3)_4$ was superior in yield (entry 4). Moreover, by heating the reaction mixture to




**Scheme 1.** Retrosynthetic analyses of cordiaquinone J and K.




**Scheme 2.** Synthesis of (±)-13-deoxocordiaquinone K. Reagents, conditions and yields. (a) (1) $H_2$, $PtO_2$, EtOAc; (2) NaH, MeI, DMF (89%, two steps); (b) (i) 2 equiv *t*-BuLi, ether, −78 °C; (ii) 2.5 equiv B-MeO-9-BBN, hexane, THF; (iii) 2.5 equiv base; (iv) 5 mol% Pd catalyst, **7**, DMF (see Table 1); (c) CAN, $CH_3CN$, 0 °C (73%).

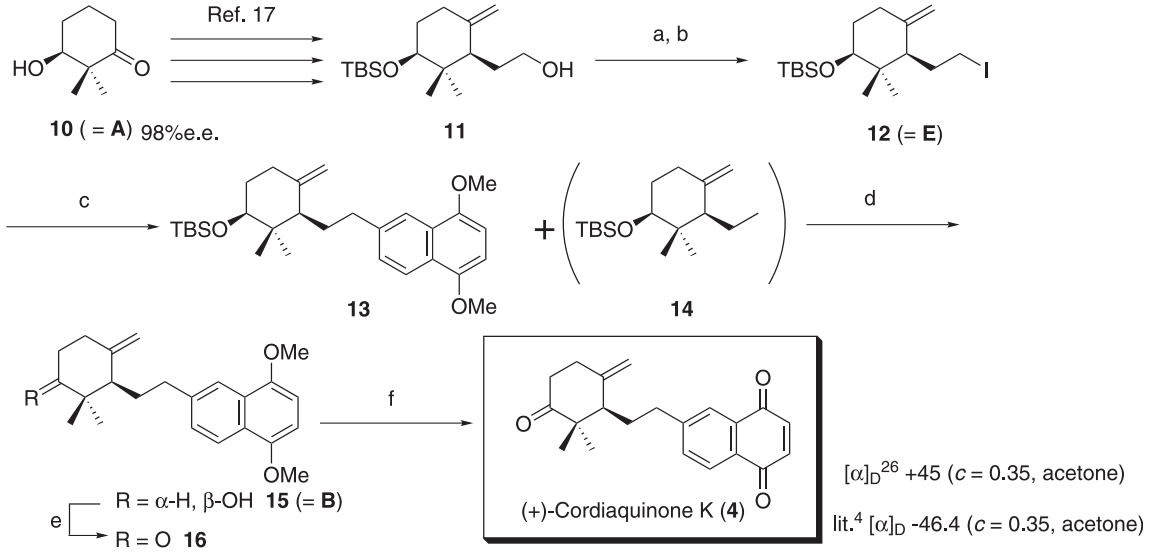
80 °C, 50% yield of **9** was obtained (entry 6). This indicates that the yield based on **7** was quantitative. Increasing the stoichiometry of **7**, however, showed only a slight improvement (55%, entry 7). Other palladium catalysts such as $Pd_2(dba)_3$, $PdCl_2(dppe)$, $PdCl_2(dppp)$, $Pd(PEt_3)_2Cl_2$, $Pd(OAc)_2+2Cy_3P$ and allylpalladium chloride dimer or other bases such as $Ba(OH)_2$, TlOEt and $Cs_2CO_3$ were also examined, but we found $Pd(PPh_3)_4$ with $K_3PO_4$ is the best choice for the coupling reaction. With the desired product (**9**) in hand (Scheme 2), the aromatic ring of **9** was oxidized with ceric ammonium nitrate (CAN) to afford (±)-13-deoxocordiaquinone K (**5**). The spectroscopic data of synthetic **5** are in perfect accordance with the structure of **5**.

By using this established methodology as described above, the synthesis of optically active cordiaquinone K was investigated (Scheme 3). The known alcohol (**11**)[17] derived from the known hydroxyketone (**10**)[12] was selected as the starting material. Alcohol **11** was converted to the corresponding iodide **12** (=**E**) in two steps (68%). The resulting iodide **12** was coupled with **7** by using the optimized conditions described above to give coupled product **13** (50%). In the $^1H$ NMR spectrum of the crude product, we observed the signals of side products with the terminal ethyl group. The yield of the product was estimated to be 20–35%. Although the

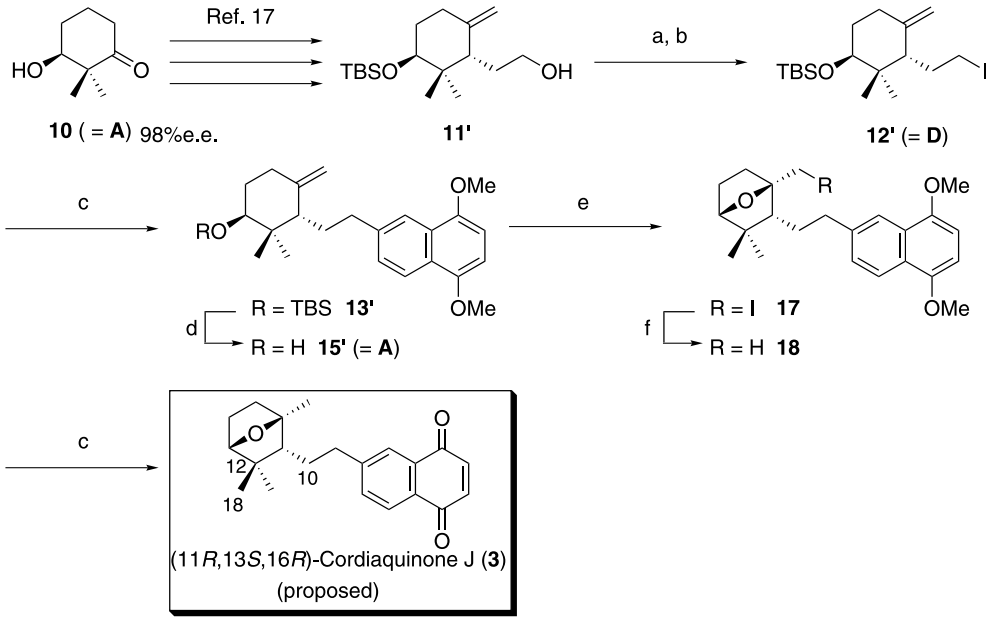
**Table 1**. Reaction conditions and yields of **9**

| Entry | Pd catalyst[a] | Equiv of **7** | Temp. (°C) | Time (h) | Yield based on **8** (%) | Yield based on **7** (%) |
|---|---|---|---|---|---|---|
| 1 | $PdCl_2(dppf)$ | 0.5 | rt | 16 | 10 | 20 |
| 2 | | 0.5 | rt | 120 | 13 | 26 |
| 3 | | 0.5 | 80 | 16 | 12 | 24 |
| 4 | $Pd(PPh_3)_4$ | 0.5 | rt | 16 | 24 | 48 |
| 5 | | 0.5 | rt | 72 | 22 | 44 |
| 6 | | 0.5 | 80 | 16 | 50 | Quant. |
| 7 | | 1 | 80 | 16 | 55 | 55 |
| 8 | | 2 | 80 | 16 | 50 | 25 |

[a] Five mole percent of catalysts with 2.5 equiv of $K_3PO_4$ were used.




**Scheme 3.** Synthesis of (+)-cordiaquinone K. Reagents, conditions and yields. (a) TsCl, Py.; (b) NaI, acetone, reflux (68%, two steps); (c) (i) 2 equiv *t*-BuLi, ether, −78 °C; (ii) 2.5 equiv B-MeO-9-BBN, hexane, THF; (iii) 3 M $K_3PO_4$; (iv) 5 mol% $Pd(PPh_3)_4$, **7**, DMF, 80 °C, 16 h (50%); (d) TBAF, THF, 60 °C (90%); (e) PCC, MS4A, $CH_2Cl_2$ (63%); (f) CAN, $CH_3CN$, 0 °C (quant.).




**Scheme 4.** Synthesis of (11*R*,13*S*,16*R*)-cordiaquinone J. Reagents, conditions and yields. (a) TsCl, Py.; (b) NaI, acetone, reflux (77%, two steps); (c) (i) 2 equiv *t*-BuLi, ether, −78 °C; (ii) 2.5 equiv B-MeO-9-BBN, hexane, THF; (iii) 3 M $K_3PO_4$; (iv) 5 mol% $Pd(PPh_3)_4$, **7**, DMF, 80 °C, 16 h (43%); (d) TBAF, THF, 60 °C (93%); (e) NIS, $CH_3CN$, (75%); (f) *n*-$Bu_3SnH$, AIBN, benzene, reflux (84%); (g) CAN, $CH_3CN$, 0 °C (72%).

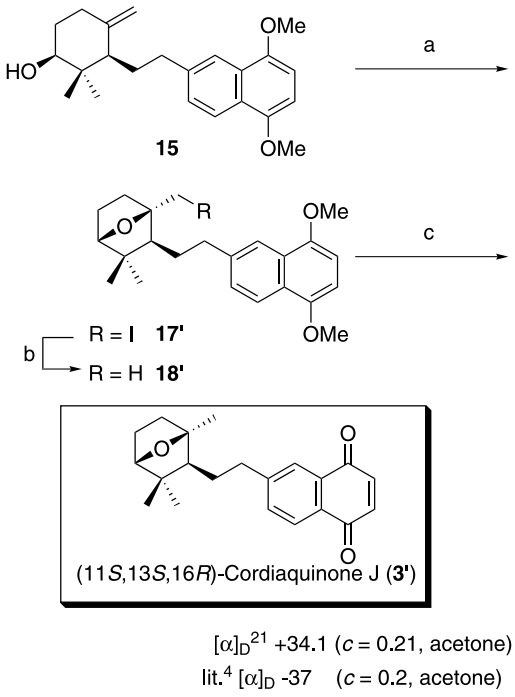
isolation of this compound was unsuccessful due to other side products, this compound was presumed to be compound **14**, which might be produced by protonation of lithiated **12**. This result indicates that optimization of the lithium–boron exchange procedure could improve the yield of this step.[18] The obtained coupling product **13** was treated with TBAF at 60 °C to give alcohol **15** (=**B**) (90%). Finally, the resulting hydroxyl group was oxidized with PCC (63%) and subsequent oxidation of the aromatic ring with CAN at 0 °C gave (*R*)-(+)-cordiaquinone K (**4**) as a pale yellow gum in quantitative yield. The overall yield of (+)-**4** was 19% in six steps from known alcohol (**11**). The $^1H$ and $^{13}C$ NMR and MS spectra are identical with those of reported data[4]. Synthetic cordiaquinone K (**4**) shows $[\alpha]_D^{26}$ +45 (*c* 0.35, acetone), while natural cordiaquinone K shows $[\alpha]_D$ −46.4 (*c* 0.35, acetone)[4]. This means that our synthetic cordiaquinone K is the antipode of the natural product. The absolute configuration of natural cordiaquinone K is, therefore, determined to be *S*.

In order to determine the relative and absolute configuration, we set out to synthesize cordiaquinone J (Scheme 4). We first choose (11*R*,13*S*,16*R*)-**3** as a candidate of the natural product. This compound possesses a cis naphtoquinone-substituted side chain at C-11 and a methyl group at C-16 as originally indicated by Hostettmann (Fig. 1).[4] The absolute configuration at C-11 of **3** was presumed to be the same as that of natural (*S*)-(−)-cordiaquinone K, because cordiaquinones could be biosynthesized from a common intermediate. For the synthesis of **3**, we selected known alcohol **11′**, diastereomer of the intermediate of our synthesis of cordiaquinone K (**4**), as a starting material. Alcohol **11′** was converted to the corresponding iodide **12′** (=**D**) as described above (77%, in two steps). The iodide **12′** was coupled with **7** using one-pot *B*-alkyl Suzuki–Miyaura coupling strategy to give **13′** (43%). Removal of the TBS group to give **15′** (93%) was followed by construction of an oxabicyclo ring system. Namely, intermolecular iodo-etherification by treatment with *N*-iodosuccinimide (NIS) gave **17** (75%), then radical reduction of **17** by tri-*n*-butyltinhydride afforded **18** with the desired oxabicyclo ring system (84%). Finally, oxidation of the aromatic ring with CAN gave (11*R*,13*S*,16*R*)-cordiaquinone J (**3**) in 72% yield. The overall yield of (11*R*,13*S*,16*R*)-**3** was 14% in seven steps from known alcohol **11′**. The $^1H$ NMR and IR spectra of synthetic (11*R*,13*S*,16*R*)-cordiaquinone J (**3**) are in good accordance with those of the natural product. But the $^{13}C$ NMR spectrum of synthetic **3** is not identical with those of the natural product. Table 2 summarizes selected $^{13}C$ NMR chemical shift values of synthetic and natural cordiaquinone J. Remarkable differences are observed at C-10, C-12 and C-18, which are located around the oxabicyclo ring system. So, we concluded that our synthetic **3** is a diastereomer of the natural cordiaquinone J.

To prove this hypothesis, we decided to synthesize a diastereomer of **3**. Since we have already synthesized compound **15** as an intermediate of (*R*)-(+)-cordiaquinone K (Scheme 1), we chose **15** as starting material for the

**Table 2**. 100 MHz $^{13}C$ NMR chemical shifts of synthetic (11*R*,13*S*,16*R*)- and natural cordiaquinone J

| Carbon number | Synthetic (ppm) | Natural (ppm) |
|---|---|---|
| 9 | 29.6 | 36.8 |
| 10 | 27.3 | 30.3 |
| 11 | 57.6 | 56.2 |
| 12 | 42.5 | 46.0 |
| 13 | 86.5 | 86.4 |
| 14 | 29.5 | 26.3 |
| 15 | 36.5 | 39.7 |
| 16 | 88.2 | 86.9 |
| 17 | 20.0 | 19.2 |
| 18 | 32.8 | 26.2 |
| 19 | 21.8 | 23.6 |




**Scheme 5.** Synthesis of (11*S*,13*S*,16*R*)-cordiaquinone J. Reagents, conditions and yields. (a) NIS, $CH_3CN$, 0 °C (74%); (b) *n*-$Bu_3SnH$, AIBN, benzene, reflux (quant.); (c) CAN, $CH_3CN$ (70%).

synthesis of (11*S*,13*S*,16*R*)-cordiaquinone J (**3′**). Scheme 5 summarizes the synthesis of (11*S*,13*S*,16*R*)-cordiaquinone J (**3′**). In the same manner of the synthesis of (11*R*,13*S*,16*R*)-isomer, **15** was converted to **3′** in three steps. All spectral data such as IR and $^1H$ and $^{13}C$ NMR of synthetic **3′** are identical with those of the natural product. Synthetic **3′** shows $[\alpha]_D^{21}$ +34 (*c* 0.21, acetone), while the natural cordiaquinone J shows $[\alpha]_D$ −37 (*c* 0.2, acetone)[4]. This means that our synthetic cordiaquinone J is the antipode of the natural product. The absolute configuration of natural cordiaquinone J is, therefore, determined to be 11*R*,13*R*,16*S*.

## 3. Conclusion

A versatile methodology for terpenoid synthesis was established by using one-pot *B*-alkyl Suzuki–Miyaura coupling reaction. With this methodology, synthesis of (*R*)-cordiaquinone K was achieved. The absolute configuration of the natural cordiaquinone K (**4**) was determined to be *S* by a comparison of optical rotations of the synthetic and natural products. We also synthesized (11*R*,13*S*,16*R*)- and (11*S*,13*S*,16*R*)-cordiaquinone J (**3** and **3′**). The absolute stereochemistry of natural cordiaquinone J was determined to be 11*R*,13*R*,16*S*. Both the natural cordiaquinone K and J possess the same stereochemical feature at C-11. This suggests that cordiaquinones would be biosynthesized from a common intermediate.

## 4. Experimental

### 4.1. General

Optical rotations were measured on a Jasco DIP-140. IR spectra were measured for samples as films for oils or as KBr plates for solids on a Shimadzu IR-470 spectrometer. $^1H$ NMR spectra were taken with Jeol JNM-A400 (400 MHz) spectrometer using $CDCl_3$ at $\delta=7.24$ or acetone-$d_6$ at $\delta=2.04$ as an internal standard. $^{13}C$ NMR spectra were taken with Jeol JNM-A400 (100 MHz) spectrometer using $CDCl_3$ at $\delta=77.0$ or acetone-$d_6$ at $\delta=29.8$ as an internal standard. HRMS spectra were measured on a Jeol-MS700 spectrometer and Jeol-HX110/110A spectrometer. Elemental compositions were analyzed on a J-Science MICROCORDER JM10. Column chromatography was performed with silica gel Wakogel-C200.

**4.1.1. 6-Bromo-1,4-dimethoxynaphthalene (7).** To a solution of **6** (700 mg, 2.95 mmol) in EtOAc (10 ml), $PtO_2$ (15 mg) was added. The stirred suspension was degassed by evacuating, and filled with $H_2$. After stirring for 3 h, the suspension was filtered through Celite pad and concentrated in vacuo. The residue was dissolved in DMF (10 ml), and added MeI (460 µl, 11.8 mmol) and 60% NaH in oil (443 mg, ca. 12 mmol) to the solution. After stirring overnight, the mixture was poured into water and extracted with EtOAc three times. The combined organic extracts were washed with water and dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (hexane/EtOAc=100:1) to afford 700 mg (89%) of **7** as a colorless amorphous solid. IR (KBr) $\nu_{max}$ ($cm^{-1}$)=3000 (w, H–C=C), 2950 (m, C–H), 1625 (m), 1590 (s), 1460 (s), 1420 (s), 1365 (s), 1330 (m), 1150 (m), 1100 (s), 1080 (s), 960 (m), 860 (m), 830 (m), 800 (s), 760 (m), 720 (m), 440 (s); $^1H$ NMR (400 MHz, $CDCl_3$): $\delta=3.92$ (s, 6H, 1, 4-$OCH_3$), 6.66 (d, $J=8.3$ Hz, 1H, 2-H), 6.69 (d, $J=8.3$ Hz, 1H, 3-H), 7.54 (dd, $J=2.4$, 8.8 Hz, 1H, 7-H), 8.05 (d, $J=8.8$ Hz, 1H, 8-H), 8.35 (d, $J=2.4$ Hz, 1H, 5-H). Found C, 53.95%; H, 4.15%. Calcd for $C_{12}H_{11}BrO_2$: C, 53.96%; H, 4.15%.

**4.1.2. *B*-Alkyl Suzuki–Miyaura coupling reaction of iodide (8, 12 and 12′) and bromonaphthoquinone derivative (7).** *General procedure*. To a stirred and cooled (−78 °C) solution of iodide in dry ether was added dropwise *tert*-BuLi in pentane (2.5 equiv) under Ar. After stirring for 30 min, *B*-methoxy-9-borabicyclo[3.3.1]nonane in hexane (1.5 equiv) was added dropwise, followed by addition of dry THF. After stirring for 10 min at the same temperature, the resulting solution was allowed to warm to rt for 75 min To the mixture, aqueous 3 M $K_3PO_4$ solution (2.5 equiv) was added, followed by a solution of **7** (1 equiv) in DMF. After addition of $Pd(PPh_3)_4$ (0.05 equiv), the mixture was stirred at 80 °C for 16 h. After cooling to rt, the mixture was diluted with ether. The organic layer was washed with water and brine, and the combined aqueous layers were extracted with ether three times. The combined organic layers were dried with $Na_2SO_4$. After concentration in vacuo, the residue was purified by column chromatography (hexane) to afford **9**, **12** or **12′** as a colorless oil or amorphous solid.

**4.1.3. (±)-6-[2′-(6″,6″-Dimethyl-2″-methylenecyclohexyl)-ethyl]-1,4-dimethoxynaphthalene (9).** Yield: 55%; amorphous solid; IR (KBr) $\nu_{max}$ ($cm^{-1}$)=3080 (m, H–C=C), 2920 (s, C–H), 1645 (m), 1635 (m), 1610 (s, Ar–O–$CH_3$), 1460 (s), 1390 (s), 1345 (m), 1270 (s), 1165 (m), 1090 (m), 1000 (m), 970 (m), 895 (s), 825 (s), 795 (s), 715

(m); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.81 (s, 3H, 6″-$CH_3$), 0.89 (s, 3H, 6″-$CH_3$), 1.71–1.99 (m, 7H, 2′, 4″, 5″-$CH_2$), 2.05 (m, 1H, 3″-C*H*H), 2.06 (m, 1H, 3″-CH*H*), 2.50 (m, 1H, 1′-C*H*H), 2.75 (m, 1H, 1′-CH*H*), 3.93, 3.94 (2×s, 6H, 2×$CH_3$–O), 4.64 (br s, 1H, H–C=C), 4.83 (br s, 1H, H–C=C), 6.60, 6.66 (d, $J$=8.6 Hz, 2H, 2,3-H), 7.29 (dd, $J$=2.0, 8.8 Hz, 1H, 7-H), 7.94 (d, $J$=2.9 Hz, 1H, 5-H), 8.07 (d, $J$=8.8 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=23.7, 26.4, 28.3, 28.7, 32.4, 34.88, 34.93, 36.1, 53.9, 55.70, 55.70, 102.3, 103.2, 109.3, 120.2, 121.7, 124.7, 126.4, 127.3, 141.0, 149.19, 149.23, 149.6; HRFABMS: Calcd for $C_{23}H_{30}O_2$ $[M]^+$: 338.2246, found: 338.2243.

**4.1.4. (1″*R*,3″*S*)-6-[2′-(3″-*tert*-Butyldimethylsilyloxy-2″,2″-dimethyl-6″-methlenecyclohexyl)-ethyl]-1,4-dimethoxynaphthalene (13).** Yield: 50%; oil; $[\alpha]_D^{25}$ +3.9° ($c$=0.98, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1645 (m), 1635 (s), 1605 (s), 1460 (s), 1385 (s), 1270 (s), 1240 (s), 1210 (w), 1190 (w), 1140 (w), 1030 (w), 1000 (m), 985 (s), 845 (s), 795 (m), 770 (s), 720 (m), 670 (w); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.00 (s, 3H, $SiCH_3$), 0.01 (s, 3H, Si–$CH_3$), 0.76 (s, 3H, 2″-$CH_3$), 0.87 [s, 9H, $SiC(CH_3)_3$], 0.89 (s, 3H, 2″-$CH_3$), 1.48–2.08 (m, 6H, 2′, 5″-$CH_2$, 1″-H, 4″-C*H*H), 2.39 (m, 1H, 4″-CH*H*), 2.51 (m, 1H, 1′-C*H*H), 2.87 (m, 1H, 1′-CH*H*), 3.41 (dd, $J$=3.7, 7.6 Hz, 1H, 3″-H), 3.94 (s, 6H, 1, 4-$CH_3O$), 4.69 (br s, 1H, H–C=C), 4.89 (br s, 1H, H–C=C), 6.61 (d, $J$=8.3 Hz, 1H, 2-H), 6.68 (d, $J$=8.3 Hz, 1H, 3-H), 7.33 (dd, $J$=1.3, 8.8 Hz, 1H, 7-H), 7.95 (d, $J$=1.3 Hz, 1H, 5-H), 8.09 (d, $J$=8.8 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=−5.0, −4.2, 18.0, 18.8, 25.8, 26.9, 28.1, 29.7, 30.8, 32.2, 37.1, 40.5, 52.1, 55.6, 102.2, 103.1, 108.7, 120.2, 121.6, 124.6, 126.4, 127.3, 140.9, 148.1, 149.2, 149.5.

**4.1.5. (1″*S*,3″*S*)-6-[2′-(3″-*tert*-Butyldimethylsilyloxy-2″,2″-dimethyl-6″-methlenecyclohexyl)-ethyl]-1,4-dimethoxynaphthalene (13′).** Yield: 40%; oil; $[\alpha]_D^{21}$ +14.4° ($c$ 0.202, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, C=C–H), 2950 (s, C–H), 2850 (s, C–H), 1645 (m, C=C), 1600 (s, C=C); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=−0.02 [s, 6H, $Si(CH_3)_2$], 0.84 [s, 9H, $SiC(CH_3)_3$], 0.85 [s, 6H, 2″-$(CH_3)_2$], 1.48–2.08 (m, 6H, 2′, 5″-$CH_2$, 1″-H, 4″-C*H*H), 2.39 (m, 1H, 4″-CH*H*), 2.51 (m, 1H, 1′-C*H*H), 2.87 (m, 1H, 1′-CH*H*), 3.56 (dd, $J$=4.2, 9.0 Hz, 1H, 3″-H), 3.93 (s, 3H, $CH_3O$), 3.95 (s, 3H, $CH_3O$), 4.66 (br s, 1H, H–C=C), 4.86 (br s, 1H, H–C=C), 6.62 (d, $J$=8.3 Hz, 1H, 2-H), 6.66 (d, $J$=8.3 Hz, 1H, 3-H), 7.33 (dd, $J$=1.3, 8.8 Hz, 1H, 7-H), 7.95 (d, $J$=1.3 Hz, 1H, 5-H), 8.11 (d, $J$=8.8 Hz, 1H, 8-H). Found C, 74.47%; H, 9.21%. Calcd for $C_{29}H_{44}SiO_3$: C, 74.31%; H, 9.46%.

**4.1.6. (±)-13-Deoxocordiaquinone K (5).** To a stirred solution of **9** (100 mg, 300 μmol) in MeCN/water=4:1 (15 ml) at 0 °C was added ceric ammonium nitrate (329 mg, 600 μmol) in several portions and the mixture was stirred for 30 min Then, the mixture was poured into water and extracted with ether three times. The extract was washed with water and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:50) to afford **5** (65 mg, 73%) as a pale yellow gum; IR (film) $\nu_{max}$ ($cm^{-1}$)=3070 (w, H–C=C), 2930 (s, C–H), 2860 (m, C–H), 1670 (s, C=O), 1600 (s), 1450 (m), 1390 (w), 1370 (m), 1305 (s), 1140 (w), 1045 (m), 890 (m), 835 (m), 735 (m); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.82 (s, 3H, 19-$CH_3$), 0.89 (s, 3H, 18-$CH_3$), 1.22–1.80 (m, 7H, 10,13,14-$CH_2$, 11-H), 2.05 (m, 2H, 15-$CH_2$), 2.50 (m, 1H, 9-C*H*H), 2.14 (m, 1H, 9-CH*H*), 4.60 (br s, 1H, H–C=C), 4.84 (br s, 1H, H–C=C), 6.93 (s, 2H, 2,3-H), 7.52 (dd, $J$=1.5, 8.3 Hz, 1H, 7-H), 7.86 (d, $J$=1.5 Hz, 1H, 5-H), 7.97 (d, $J$=8.3 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=23.6, 26.5, 28.1, 28.3, 32.2, 34.8, 34.9, 35.9, 53.8, 109.7, 126.1, 126.7, 129.9, 131.2, 134.1, 138.5, 138.8, 148.7, 150.5, 184.9, 185.5; HRFABMS: Calcd for $C_{21}H_{24}O_2$ $[M]^+$: 308.1777, found: 308.1810.

## 4.2. Synthesis of (*R*)-(+)-cordiaquinone K (4)

**4.2.1. (1′*R*,3′*S*)-2-(3′-*tert*-Butyldimethylsilyloxy-2′,2′-dimethyl-6′-methylenecyclohexyl)iodoethane (12).** To a stirred and ice-cooled solution of **11** (990 mg, 3.32 mmol) in dry pyridine (10 ml), *p*-TsCl (769 mg, 4.03 mmol) was added in one portion. The mixture was stirred overnight at 4 °C, then poured into water. The aqueous layer was extracted with ether three times. The combined extracts were washed with satd $CuSO_4$ aq, water and brine, and dried with $MgSO_4$. After concentration in vacuo, the residue was dissolved in dry acetone (15 ml). To the solution, NaI (970 mg, 6.47 mmol) was added, and the mixture was refluxed for 4 h. After being cooled to rt, the mixture was poured into water, and extracted with pentane three times. The combined extracts were washed with satd $NaHCO_3$ aq, satd $Na_2S_2O_3$ aq, water and brine, and dried with $Na_2SO_4$. After concentration in vacuo, the residue was purified by column chromatography (pentane) to give 923 mg of **12** (68%) as a colorless oil; IR (film) $\nu_{max}$ ($cm^{-1}$)=2950 (s, C–H), 2850 (s, C–H), 1645 (m), 1470 (s), 1385 (m), 1360 (m), 1250 (s), 1080 (s), 1000 (m), 990 (m), 935 (s), 875 (s), 670 (w); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.01 [s, 6H, $Si(CH_3)_2$], 0.82 (s, 3H, 2′-$CH_3$), 0.87 [s, 9H, $SiC(CH_3)_3$], 0.89 (s, 3H, 2′-$CH_3$), 1.46 (m, 1H, 4′-C*H*H), 1.72 (m, 1H, 4′-CH*H*), 1.82 (dd, $J$=2.4, 11.7 Hz, 1H, 1′-H), 1.95 (m, 2H, 5′-$CH_2$), 2.18 (m, 1H, 2-C*H*H), 2.31 (m, 1H, 2-CH*H*), 2.91 (ddd, $J$=7.3, 9.3, 16.6 Hz, 1H, 1-C*H*HI), 3.26 (ddd, $J$=3.9, 8.8, 16.6 Hz, 1H, 1-CH*H*I), 3.50 (dd, $J$=3.9, 5.9 Hz, 1H, 3′-H), 4.62 (br s, 1H, H–C=C), 4.81 (br s, 1H, H–C=C). This was employed in the next step without further purification.

**4.2.2. (1″*R*,3″*S*)-6-[2′-(3″-Hydroxy-2″,2″-dimethyl-6″-methlenecyclohexyl)-ethyl]-1,4-dimethoxynaphthalene. (15).** A solution of **6** (235 mg, 503 μmol) and TBAF (1 ml, 1 mmol, 1.0 M in THF) in dry THF (2 ml) was stirred at 50–60 °C for 6 h under Ar. After being cooled to rt, water was added, and the mixture was extracted with ether three times. The organic extracts were washed with water and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:10) to furnish **7′** (160 mg, 90%) as a colorless oil; $[\alpha]_D^{21}$ −21° ($c$ 0.56, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=3450 (br m, O–H), 3080 (w H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1645 (m), 1610 (s) 1460 (s), 1370 (s), 1275 (s), 1240 (s), 1210 (m), 1195 (m), 1160 (w), 1095 (s), 1020 (m), 1005 (m), 990 (m), 930 (m), 900 (s), 820 (m); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.71 (s, 3H, 2″-$CH_3$), 1.00 (s, 3H, 2″-$CH_3$), 1.53 (m, 1H, 4″-C*H*H), 1.75 (br d, $J$=11.7 Hz,

1H, 1″-H), 1.81–1.95 (m, 3H, 2′-$CH_2$, 4″-CH*H*), 2.03 (ddd, $J$=4.9, 11.7, 13.2 Hz, 1H, 5″-C*H*H), 2.36 (ddd, $J$=4.9, 4.9 13.2 Hz, 1H, 5″-CH*H*), 2.56 (ddd, $J$=7.3, 9.3, 14.2 Hz, 1H, 1′-CH*H*), 2.93 (ddd, $J$=4.9, 9.8, 14.2 Hz, 1H, 1′-CH*H*), 3.39 (dd, $J$=4.4, 9.8 Hz, 1H, 3″-H), 3.94 (s, 3H, $CH_3O$), 3.95 (s, 3H, $CH_3O$), 4.77 (br s, 1H, H–C=C), 4.98 (br s, 1H, H–C=C), 6.62 (d, $J$=8.3 Hz, 1H, 2-H), 6.66 (d, $J$=8.3 Hz, 1H, 3-H), 7.34 (dd, $J$=1.7, 8.3 Hz, 1H, 7-H), 7.96 (d, $J$=1.7 Hz, 1H, 5-H), 8.11 (d, $J$=8.3 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=15.6, 25.9, 27.5, 32.1, 32.9, 35.2, 40.5, 51.1, 55.7, 102.3, 103.2, 108.7, 120.2, 121.8, 124.7, 126.4, 127.2, 140.6, 147.1, 149.1, 149.5. Found: C, 77.96%; H, 8.47%. Calcd for $C_{23}H_{30}O_3$: C, 77.93%; H, 8.53%.

**4.2.3. (*R*)-6-[2′-(2″,2″-Dimethyl-6″-methylen-3″-oxocyclohexyl)ethyl]-1,4-dimethoxynaphthalene (16).** To a stirred solution of **15** (65 mg, 0.18 mmol) in dry $CH_2Cl_2$ (1.5 ml), powdered MS 4A (24 mg) and PCC (80 mg, 0.37 mmol) were added, respectively, at rt. After stirring for 30 min, the mixture was filtered through Celite pad, and the filtrate was concentrated in vacuo. The residue was purified by column chromatography (AcOEt/hexane=50:1) to give **16** (41 mg, 63%) as a colorless oil; $[\alpha]_D^{24}$ +55.0° ($c$ 0.34, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1710 (s, C=O), 1610 (s), 1460 (s), 1370 (s), 1270 (s), 1100 (s), 900 (s), 800 (s), 720 (s); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.97 (s, 3H, 2″-$CH_3$), 1.13 (s, 3H, 2″-$CH_3$), 1.51 (m, 1H, 2′-C*H*H), 1.85 (m, 1H, 2′-CH*H*), 2.16 (dd, $J$=3.4, 8.3 Hz, 1H, 1″-H), 2.27 (m, 1H, 4″-C*H*H), 2.43–2.60 (m, 4H, 1′,5″-$CH_2$), 2.73 (m, 1H, 4″-CH*H*), 3.88, 3.89 (2×s, 6H, 2×$CH_3O$), 4.86 (br s, 1H, H–C=C), 5.05 (br s, 1H, H–C=C), 6.57 (d, $J$=8.8 Hz, 1H, 2-H), 6.62 (d, $J$=8.3 Hz, 1H, 3-H), 7.24 (dd, $J$=1.5, 6.8 Hz, 1H, 7-H), 7.84 (d, $J$=1.5 Hz, 1H, 5-H), 8.05 (d, $J$=8.3 Hz, 1H, 8-H). This was employed in the next step without further purification.

**4.2.4. (*R*)-(+)-Cordiaquinone K (4).** To a stirred solution of **16** (37 mg, 106 μmol) in MeCN/water=4:1 (0.5 ml) at 0 °C was added ceric ammonium nitrate (126 mg, 229 μmol) in several portions and the mixture was stirred for 2.5 h. Then, the mixture was poured into water and extracted with ether three times. The extract was washed with water and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:40) to afford **4** (36 mg, quant.) as a pale yellow gum; $[\alpha]_D^{26}$ +44.9 ($c$ 0.35, acetone), lit.[4]: $[\alpha]_D$ −46.4° ($c$ 0.35, acetone); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1710 (s, C=O), 1670 (m), 1600 (s), 1420 (s), 1310 (m), 935 (m), 900 (m); $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$=0.99 (s, 3H, 19-$CH_3$), 1.18 (s, 3H, 18-$CH_3$), 1.49 (m, 1H, 10-C*H*H), 1.94 (m, 1H, 10-CH*H*), 2.24 (m, 1H, 14-C*H*H), 2.34 (dd, $J$=3.7, 12.0 Hz, 1H, 11-H), 2.55–2.98 (m, 5H, 9, 15-$CH_2$, 14-CH*H*), 4.94 (br s, 1H, H–C=C), 5.13 (br s, 1H, H–C=C), 6.88 (s, 2H, 2, 3-H), 7.58 (dd, $J$=1.8, 6.4 Hz, 1H, 7-H), 7.71 (d, $J$=1.8 Hz, 1H, 5-H), 7.82 (d, $J$=7.8 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, acetone-$d_6$): $\delta$=21.6 (C-19), 27.4 (C-18), 29.9 (C-10), 31.1 (C-15), 34.6 (C-9), 38.0 (C-14), 49.4 (C-12), 56.7 (C-11), 113.9 (C-17), 126.5 (C-5), 127.0 (C-8), 130.9 (C-8a), 132.9 (C-4a), 134.9 (C-7), 139.3 (C-3), 139.5 (C-2), 150.2 (C-6), 185.4 (C-4), 185.7 (C-1), 213.6 (C-13); HREIMS: Calcd for $C_{21}H_{22}O_3$ $[M]^+$: 322.1569, found: 322.1581; $^1$H and $^{13}$C NMR spectra are identical with those of reported natural product.

### 4.3. Synthesis of (11*R*,13*S*,16*R*)-cordiaquinone J (3)

**4.3.1. (1′*S*,3′*S*)-2-(3′-*tert*-Butyldimethylsilyloxy-2′,2′-dimethyl-6′-methylenecyclohexyl)-iodoethane (12′).** In the same manner as described above for (1′*R*,3′*S*)-isomer, 5.28 g (18.8 mmol) of **11′** was converted to **12′** to give 5.91 g (77%, two steps); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1645 (m, C=C), 1600 (s, C=C), 1485 (s, Si–$CH_3$), 1385 (s, Si–$CH_3$), 1285 (s, Si–$CH_3$), 1240 (s, C–I), 1100 (s, Si–O), 680 (w, C–I); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.01 [s, 6H, Si($CH_3$)$_2$], 0.82 (s, 3H, 2′-$CH_3$), 0.86 [s, 12H, 2′-$CH_3$, SiC($CH_3$)$_3$], 1.45 (m, 1H, 4′-C*H*H), 1.63 (m, 1H, 4′-CH*H*), 1.80–2.05 (m, 3H, 2-$CH_2$, 5′-C*H*H), 2.08 (dd, $J$=3.2, 11.5 Hz, 1H, 1′-H), 2.19 (ddd, $J$=5.4, 5.4, 13.7 Hz, 1H, 5′-CH*H*), 2.92 (dd, $J$=8.3, 17.6 Hz, 1H, 1-C*H*HI), 3.22 (ddd, $J$=3.9, 8.8, 17.6 Hz, 1H, 1-CH*H*I), 3.49 (dd, $J$=3.9, 8.8 Hz, 1H, 3′-H), 4.63 (br s, 1H, H–C=C), 4.82 (br s, 1H, H–C=C). This was employed in the next step without further purification.

**4.3.2. (1″*S*,3″*S*)-6-[2′-(3″-hydroxy-2″,2″-dimethyl-6″-methlenecyclohexyl)-ethyl]-1,4-dimethoxynaphthalene (15′).** In the same manner as described above for (1′*R*,3′*S*)-isomer, 117 mg (244 μmol) of **13′** was converted to **15′** (83 mg, 93%) as a colorless oil; $[\alpha]_D^{21}$ −15.7° ($c$ 0.328, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=3450 (br m, O–H), 3080 (w, H–C=C), 2950 (s, C–H), 2850 (s, C–H), 1645 (m, C=C), 1610 (s, C=C); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.88 (s, 3H, 2″-$CH_3$), 0.97 (s, 3H, 2″-$CH_3$), 1.45–1.91 (m, 4H, 2′, 4″-$CH_2$), 2.00 (dd, $J$=3.0, 12.2 Hz, 1H, 1″-H), 2.25 (m, 2H, 5″-$CH_2$), 2.49 (ddd, $J$=6.3, 10.7, 14.2 Hz, 1H, 1′-C*H*H), 2.72 (ddd, $J$=4.4, 10.7, 14.2 Hz, 1H, 1′-CH*H*), 3.63 (dd, $J$=4.4, 10.3 Hz, 1H, 3″-H), 3.93 (s, 3H, $CH_3O$), 3.94 (s, 3H, $CH_3O$), 4.69 (br s, 1H, H–C=C), 4.88 (br s, 1H, H–C=C), 6.62 (d, $J$=8.3 Hz, 1H, 2-H), 6.66 (d, $J$=8.3 Hz, 1H, 3-H), 7.31 (d, $J$=8.3 Hz, 1H, 7-H), 7.94 (s, 1H, 5-H), 8.09 (d, $J$=8.3 Hz, 1H, 8-H). Found: C, 78.00%, H, 8.48%. Calcd for $C_{23}H_{30}O_3$: C, 77.93%, H, 8.53%.

**4.3.3. (1*R*,2*S*,4*S*)-2-[2′-(5″,8″-Dimethoxynaphthalene-2″-yl)-ethyl]-1-iodomethyl-3,3,-dimethyl-7-oxabicyclo[2.2.1]heptane (17).** A solution of **15** (253 mg, 0.72 mmol) and *N*-iodosuccinimide (290 mg, 1.28 mmol) in dry MeCN (3 ml) was stirred at rt in the dark overnight. The resulting mixture was poured into water and extracted with ether. The extract was washed successively with $Na_2S_2O_4$ aq, water, satd $NaHCO_3$ and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:40) to afford 284 mg of **17** (83%) as a colorless oil; $[\alpha]_D^{21}$ −36.2° ($c$ 0.302, $CHCl_3$); IR (film) $\upsilon_{max}$ ($cm^{-1}$)=2950 (s, C–H), 1635 (m), 1600 (s), 1465 (s), 1425 (m), 1365 (s), 1340 (w), 1270 (s), 1245 (s), 1215 (m), 1195 (s), 1160 (w), 1095 (s), 1000 (m), 980 (m), 965 (w), 950 (m), 820 (m), 795 (s), 715 (s); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=1.00 (s, 3H, 3-$CH_3$), 1.15 (s, 3H, 3-$CH_3$), 1.52 (m, 2H, 1′-$CH_2$), 1.68 (m, 4H, 6-$CH_2$, 5-C*H*H, 2-CH), 1.95 (m, 1H, 5-CH*H*), 2.68 (m, 1H, 2′-C*H*H), 2.82 (ddd, $J$=4.0, 9.2, 9.2 Hz, 1H, 2′-CH*H*), 3.48 (d, $J$=10.7 Hz, 1H, C*H*H-I), 3.53 (d, $J$=10.7 Hz, 1H, CH*H*-I), 3.85 (d, $J$=4.9 Hz, 1H, 4-H), 3.93, 3.95 (2×s, 3H,

2×$CH_3O$), 6.63 (d, $J$=8.3 Hz, 1H, 6″-H), 6.68 (d, $J$=8.3 Hz, 1H, 7″-H), 7.32 (d, $J$=8.3 Hz, 1H, 3″-H), 7.95 (s, 1H, 1″-H), 8.12 (d, $J$=8.3 Hz, 1H, 4″-H). Found: C, 57.52%; H, 6.04%. Calcd for $C_{23}H_{29}O_3I$: C, 57.51%; H, 6.08%.

**4.3.4. (1*R*,2*S*,4*S*)-2-[2′-(5″,8″-Dimethoxynaphthalene-2″-yl)-ethyl]-1,3,3-trimethyl-7-oxabicyclo[2.2.1]heptane (18).** To a stirred solution of **16** (57 mg, 119 μmol) in dry benzene (1.5 ml) was added *n*-$Bu_3SnH$ (80 μl, 297 μmol) and AIBN (32 mg, 196 μmol) under Ar. Then the mixture was stirred at reflux for 5 h. After cooling to rt, the mixture was poured into water and extracted with ether. The extract was washed with water, satd $NaHCO_3$ and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:50) to afford **18** (98 mg, 84%) as a colorless oil; $[\alpha]_D^{21}$ −9.3° (*c* 0.33, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=2950 (s, C–H), 1635 (s), 1605 (s), 1465 (s), 1425 (s), 1370 (s), 1340 (m), 1270 (s), 1245 (s), 1215 (s), 1195 (s), 1160 (m), 1140 (w), 1095 (s), 1000 (s), 980 (m), 965 (w), 950 (m), 895 (w), 860 (w), 820 (m), 795 (s), 715 (s); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=0.98 (s, 3H, 3-$CH_3$), 1.11 (s, 3H, 3-$CH_3$), 1.14–1.24 (m, 2H, 2-H, 6-C*H*H), 1.35 (m, 1H, 6-CH*H*), 1.39 (s, 3H, 1-$CH_3$), 1.50–1.70 (m, 3H, 5-C*H*H, 1′-$CH_2$), 1.80 (m, 1H, 5-CH*H*), 2.68 (ddd, $J$=6.3, 10.7, 13.7 Hz, 1H, 2′-C*H*H), 2.78 (ddd, $J$=4.9, 11.2, 13.7 Hz, 1H, 2′-CH*H*), 3.80 (d, $J$=5.9 Hz, 1H, 4-H), 3.93 (s, 3H, $CH_3O$), 3.95 (s, 3H, $CH_3O$), 6.62 (d, $J$=8.3 Hz, 1H, 6″-H), 6.67 (d, $J$=8.3 Hz, 1H, 7″-H), 7.33 (dd, $J$=2.0, 8.8 Hz, 1H, 3″-H), 7.95 (d, $J$=2.0 Hz, 1H, 1″-H), 8.15 (d, $J$=8.8 Hz, 1H, 4″-H). Found: C, 77.96%; H, 8.46%. Calcd for $C_{23}H_{30}O_3$: C, 77.93%; H, 8.53%.

**4.3.5. (11*R*,13*S*,16*R*)-Cordiaquinone J (3).** To a stirred solution of **17** (60 mg, 169 μmol) in MeCN/water=4:1 (1 ml) at 0 °C was added CAN (187 mg, 341 μmol) in several portions and the mixture was stirred for 2 h. Then, the mixture was poured into water and extracted with ether three times. The extract was washed with water and brine, then dried with $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography (AcOEt/hexane=1:40) to afford **3** (39 mg, 72%) as a pale yellow gum; $[\alpha]_D^{21}$ –20° (*c* 0.05, acetone); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2950 (s, C–H), 2855 (m, C–H), 1665 (s, C=C–C=O), 1600 (s, C=C–C=O), 1465 (m), 1385 (m), 1340 (w), 1335 (m), 1305 (s), 1190 (w), 1135 (w), 1080 (w), 1045 (m), 995 (m), 870 (m), 835 (s); $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$=1.00 (s, 3H, 19-$CH_3$), 1.07 (s, 3H, 18-$CH_3$), 1.12 (ddd, $J$=2.0, 3.9, 12.2 Hz, 1H, 15-C*H*H), 1.31 (ddd, $J$=1.9, 4.4, 9.3 Hz, 1H, 14-C*H*H), 1.50 (dddd, $J$=5.4, 5.4, 12.7, 12.7 Hz, 1H, 10-C*H*H), 1.54–1.74 (m, 3H, 11-H, 10, 15-CH*H*), 1.83 (dddd, $J$=3.9, 4.9, 8.8, 12.2 Hz, 1H, 14-CH*H*), 2.75 (ddd, $J$=6.8, 11.3, 13.7 Hz, 1H, 9-C*H*H), 2.85 (dd, $J$=4.9, 10.3, 13.7 Hz, 1H, 9-CH*H*), 3.72 (d, $J$=4.9 Hz, 1H, 13-H), 7.00 (s, 2H, 2, 3-H), 7.66 (dd, $J$=2.0, 7.8 Hz, 1H, 7-H), 7.83 (d, $J$=2.0 Hz, 1H, 5-H), 7.88 (d, $J$=7.8 Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, acetone-$d_6$): $\delta$=20.0 (C-17), 21.8 (C-19), 27.3 (C-14), 30.3 (C-10), 30.4 (C-9), 32.9 (C-18), 36.6 (C-15), 42.6 (C-12), 57.6 (C-11), 86.6 (C-13), 88.3 (C-16), 126.4 (C-5), 127.1 (C-8), 130.9 (C-8a), 132.9 (C-4a), 134.8 (C-7), 139.4 (C-3), 139.5 (C-2), 150.6 (C-6), 185.3 (C-2), 185.7 (C-1). Found: C, 77.77%, H, 7.40%. Calcd for $C_{21}H_{24}O_3$: C, 77.75%, H, 7.46%.

### 4.4. Synthesis of (11*S*,13*S*,16*R*)-(+)-cordiaquinone J (3′)

**4.4.1. (1*R*,2*R*,4*S*)-2-[2′-(5″,8″-Dimethoxynaphthalene-2″-yl)-ethyl]-1-iodomethyl-3,3,-dimethyl-7-oxabicyclo[2.2.1]heptane (17′).** In the same manner as described above for (1*R*,2*S*,4*S*)-isomer, 160 mg (452 μmol) of **15′** was converted to **17′** (160 mg, 74%) as a colorless oil; $[\alpha]_D^{21}$ +48.8° (*c* 0.81, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=2950 (s, C–H), 1635 (s), 1600 (s), 1460 (br s), 1365 (s), 1270 (s), 1240 (s), 1210 (m), 1195 (m), 1160 (m), 1095 (s), 1000 (s), 970 (m), 955 (m), 900 (w), 860 (w), 830 (m), 800 (s), 720 (s); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=1.12 (s, 3H, 3-$CH_3$), 1.15 (s, 3H, 3-$CH_3$), 1.50–1.75 (m, 5H, 6, 1′-$CH_2$, 5-C*H*H), 1.85 (m, 1H, 5-CH*H*), 1.88 (dd, $J$=1.9, 11.2 Hz, 1H, 2-H), 2.63 (ddd, $J$=6.4, 9.8, 13.7 Hz, 1H, 2′-C*H*H), 2.80 (ddd, $J$=4.9, 10.7, 13.7 Hz, 1H, 2′-CH*H*), 3.26 (d, $J$=10.3 Hz, 1H, 1-C*H*H), 3.47 (d, $J$=10.3 Hz, 1H, 1-CH*H*), 3.86 (d, $J$=4.4 Hz, 1H, 4-H), 3.88, 3.89 (2×s, 6H, 2×$CH_3O$), 6.58 (d, $J$=8.3 Hz, 1H, 6″-H), 6.62 (d, $J$=8.3 Hz, 1H, 7″-H), 7.30 (dd, $J$=1.9, 8.3 Hz, 1H, 3″-H), 7.91 (br s, 1H, 1″-H), 8.06 (d, $J$=8.3 Hz, 1H, 4″-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=8.00, 23.5, 25.6, 26.4, 29.3, 36.2, 38.0, 46.0, 54.3, 55.7, 86.7, 87.3, 102.5, 103.3, 120.2, 122.0, 124.8, 126.4, 127.0, 139.7, 149.1, 149.5. Found: C, 57.58%; H, 6.13%. Calcd for $C_{23}H_{29}O_3I$: C, 57.51%; H, 6.08%.

**4.4.2. (1*R*,2*R*,4*S*)-2-[2′-(5″,8″-Dimethoxynaphthalene-2″-yl)-ethyl]-1,3,3-trimethyl-7-oxabicyclo[2.2.1]heptane (18′).** In the same manner as described above for (1*R*,2*S*,4*S*)-isomer, 160 mg (452 μmol) of **17′** was converted to **18′** (106 mg, quant.) as a colorless oil; $[\alpha]_D^{21}$ +27.8° (*c* 0.63, $CHCl_3$); IR (film) $\nu_{max}$ ($cm^{-1}$)=2950 (s, C–H), 1600 (s), 1460 (s), 1425 (m), 1365 (s), 1270 (s), 1240 (m), 1195 (m), 1095 (s), 1000 (w), 990 (m), 985 (w), 830 (w), 800 (s), 720 (m); $^1$H NMR (400 MHz, $CDCl_3$): $\delta$=1.10 (s, 6H, 2×3-$CH_3$), 1.30 (dd, $J$=5.9, 8.3 Hz, 1H, 2-H), 1.39–1.53 (m, 2H, 5, 6-C*H*H), 1.68 (m, 3H, 6-CH*H*, 1′-$CH_2$), 1.91 (ddd, $J$=4.9, 8.5, 12.5 Hz, 1H, 5-CH*H*), 2.69 (ddd, $J$=6.3, 9.8, 13.7 Hz, 1H, 2′-C*H*H), 2.78 (ddd, $J$=5.9, 10.2, 13.7 Hz, 1H, 2′-CH*H*), 3.80 (d, $J$=5.9 Hz, 1H, 4-H), 3.93, 3.95 (2×s, 6H, 2×$CH_3O$) 6.62 (d, $J$=8.3, 1H, 6″-H), 6.67 (d, $J$=8.3, 1H, 7″-H) 7.34 (dd, $J$=2.0, 8.8 Hz, 1H, 3″-H), 7.95 (d, $J$=2.0 Hz, 1H, 1″-H), 8.15 (d, $J$=8.8 Hz, 1H, 4″-H); $^{13}$C NMR (100 MHz, $CDCl_3$): $\delta$=19.0, 23.5, 25.7, 26.1, 29.9, 36.4, 36.5, 39.0, 45.3, 55.5, 55.7, 86.1, 86.7, 102.4, 103.3, 120.1, 121.9, 124.7, 126.4, 127.0, 140.4, 149.1, 149.5. Found: C, 77.93%; H, 8.41%. Calcd for $C_{23}H_{30}O_3$: C, 77.93%; H, 8.53%.

**4.4.3. (11*S*,13*S*,16*R*)-(+)-Cordiaquinone J (3′).** In the same manner as described above for (11*R*,13*S*,16*R*)-isomer, 79 mg (309 μmol) of **17′** was converted to **3′** (71 mg, 70%) as a pale yellow gum; $[\alpha]_D^{21}$ +34.1° (*c* 0.205, acetone), lit.[4]; $[\alpha]_D$ −37° (*c* 0.2, acetone); IR (film) $\nu_{max}$ ($cm^{-1}$)=3080 (w, H–C=C), 2995 (s, C–H), 2975 (m, C–H), 1665 (s, C=C–C=O), 1600 (s, C=C–C=O), 1460 (m), 1380 (m), 1345 (w), 1310 (s), 1190 (w), 1180 (w), 1135 (m), 1045 (m), 995 (m), 875 (m), 835 (s); $^1$H NMR (400 MHz, acetone-$d_6$): $\delta$=1.08 (s, 3H, 19-$CH_3$), 1.12 (s, 3H, 18-$CH_3$), 1.32 (s, 3H, 17-$CH_3$), 1.33–1.4 (m, 2H, 11-H, 15-C*H*H), 1.51–1.6 (m, 1H, 15-CH*H*), 1.55–1.67 (m, 2H, 10, 14-C*H*H), 1.72 (m, 1H, 10-CH*H*), 1.93 (ddd, $J$=4.9, 8.5, 12.2 Hz, 1H, 14-CH*H*), 2.80 (m, 2H, 9-$CH_2$), 3.67 (d, $J$=5.4 Hz, 1H, 13-H), 7.00 (s, 2H,

2, 3-H), 7.72 (br d, $J=7.8$ Hz, 1H, 7-H), 7.85 (s, 1H, 5-H), 7.95 (d, $J=7.8$ Hz, 1H, 8-H); $^{13}$C NMR (100 MHz, acetone-$d_6$): $\delta=19.2$ (C-17), 23.6 (C-19), 26.1 (C-18), 26.3 (C-14), 30.3 (C-10), 36.8 (C-9), 39.7 (C-15), 46.0 (C-12), 56.3 (C-11), 86.4 (C-13), 86.9 (C-16), 126.3 (C-5), 127.1 (C-8), 130.9 (C-8a), 132.9 (C-4a), 134.7 (C-7), 139.3 (C-3), 139.5 (C-2), 150.7 (C-6), 185.3 (C-4), 185.7 (C-1). Found: C, 77.71%; H, 7.42%. Calcd for $C_{21}H_{24}O_3$: C, 77.75%; H 7.46%; $^1$H and $^{13}$C NMR spectra are identical with those of reported natural product.

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