Vibralactone Biogenesis-Associated Analogues from Submerged Cultures of the Fungus *Boreostereum vibrans*

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**Abstract**
A scale-up fermentation of the fungus *Boreostereum vibrans* facilitated the isolation of six new vibralactone biogenesis-associated analogues, namely vibralactamide A (1), vibralactone T (2), 13-\(\text{O}\)-lactyl vibralactone (3), 10-\(\text{O}\)-acetyl vibralactone G (4), (11R,12R)- and (11S,12R)-vibradiol (5, 6). Their structures were established via extensive spectroscopic analyses, specific optical rotation comparison, and Snatzke’s method. The biosynthetic pathway for vibralactamide A was postulated. The absolute configuration of vibralactone B was revised by single crystal X-ray diffraction analysis. This work puts the divergent vibralactone biosynthesis pathway one step further and expands the structural diversity of vibralactone-associated compounds.

**Graphical Abstract**

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1 Introduction

Natural products from higher fungi origin are irreplaceable sources of architecturally distinct scaffolds for drug discovery [1, 2]. The fungus Boreostereum vibrans is featured by producing a lipase inhibitor named vibralactone which harboring an unusual \( \beta \)-lactone group. In recent years, endeavors to explore the potential of producing diverse metabolites of B. vibrans by scale-up fermentation and/or changing culture medium compositions led to the isolation of plenty of bioactive vibralactone congeners and vibralactone biosynthetic-associated compounds [3–11], including vibralactoximes A–P which represented the first class of natural oxime esters [3]. The biosynthesis of vibralactone and divergent biosynthetic pathway for skeletally distinct vibralactone-associated compounds were illuminated [12, 13]. It was proved that all these compounds shared the biosynthetic precursor 3-prenyl-4-hydroxybenzylalcohol. An FAD-binding monooxygenase (VibMO1) from B. vibrans that converted prenyl 4-hydroxybenzoate into prenylhydroquinone was also characterized for the first time.

This study, as part of our ongoing interest in bioactive metabolites from higher fungi, focused on the trace compounds of scale-up submerged cultures of B. vibrans. As a result, six previously undescribed vibralactone biogenesis-associated analogues were identified. Herein, we report the isolation, structure elucidation, and absolute configuration determination via comparison of specific optical rotations and application of Snatzke’s method of these new compounds (Fig. 1). We also make a revision of the absolute configuration of vibralactone B.

2 Results and Discussion

Compound 1 was obtained as colorless oil. It had a molecular formula \( \text{C}_{14} \text{H}_{23} \text{O}_{3} \text{N} \) as deduced from the HRMS molecular ion peak at \( m/z \) 253.1672 [M\(^+\)] (calcd for 253.1678, \( \text{C}_{14} \text{H}_{23} \text{O}_{3} \text{N} \)), indicating four degrees of hydrogen deficiency. The IR spectrum absorption bands at 3447 and 1637 cm\(^{-1}\) indicated the presence of hydroxy and carbonyl groups, respectively. The 1D NMR spectra allowed the completion of planar structure of 1. The HMBC correlations (Fig. 2) from the two methyl singlets (\( \delta_{\text{H}} \) 1.60, 1.68) to C-9 and C-10, along with the \(^1\text{H}–^1\text{H} \) COSY correlations between H-8 (\( \delta_{\text{H}} \) 2.50, 2.13) and H-9 (\( \delta_{\text{H}} \) 5.14) suggested the existence of an isopentenyl group. Analysis of the \(^1\text{H}–^1\text{H} \) COSY spectrum allowed the following sequential connectivity from C-8 to C-5, from C-3 to C-13 (Fig. 2). The HMBC correlations from H-8 to C-1 (\( \delta_{\text{C}} \) 38.3), C-2 (\( \delta_{\text{C}} \) 28.9), and C-7 revealed that the carbonyl group connected to C-1. The key HMBC correlations from H-13 (\( \delta_{\text{H}} \) 5.17) to the typical oxygenated methylene C-5 (\( \delta_{\text{C}} \) 65.7) and carbonyl C-7 as well as the chemical shift of C-13 (\( \delta_{\text{C}} \) 91.6) [14] led to the assignments of an ether bond between C-5/C-13, and a nitrogen atom between C-7/C-13, which constructed a hexahydro-furo[2,3-\(b\)]pyridin-6(2H)-one scaffold. The remaining two carbons (C-1’, \( \delta_{\text{C}} \) 49.7; C-2’, 61.5) was assigned to a 2’hydroxyethyl substituted at the nitrogen atom as supported by the \(^1\text{H}–^1\text{H} \) COSY correlations between H-1’ (\( \delta_{\text{H}} \) 3.61, 3.38) and H-2’ (\( \delta_{\text{H}} \) 3.61), and HMBC correlations from H-1’ to C-7 and C-13. When changing NMR solvents from acetone-\( \text{d}_6 \) to DMSO-\( \text{d}_6 \), the resultant 2’-OH proton signal at \( \delta_{\text{H}} \) 4.66 (t, 6 = 5.6 Hz) and less overlapped signals reinforced the above assignments.

The relative configuration of compound 1 was established by interpretation of the ROESY spectrum. Evident ROESY signals between H-3 (\( \delta_{\text{H}} \) 2.71)/H-13, H-1 (\( \delta_{\text{H}} \) 2.34)/H-4x (\( \delta_{\text{H}} \) 1.82), H-8a (\( \delta_{\text{H}} \) 2.13)/H-2\( \beta \) (\( \delta_{\text{H}} \) 1.81) indicated that the two rings were cis-fused and the isopentenyl group was \( \beta \)-oriented (Fig. 3). Therefore, compound 1 was established as shown in Fig. 1 and was trivially named as vibralactamide A.

The biosynthetic pathway of vibralactamide A (1) was proposed as shown in Scheme 1. It was supposed that 3-prenyl-4-hydroxybenzylalcohol (A) underwent a C–C cleavage reaction to give 1,5-seco-vibralactone (B). The intermediate B was then subjected to cascade reduction and oxidation reactions to give C. The key intermediate D which formed by nucleophilic addition of C with 2-aminoethanol was subjected to hydroxylation/nucleophilic addition/dihydroxylation processes to afford compound 1.

Compound 2 was obtained as colorless oil. The molecular formula was established as \( \text{C}_{14} \text{H}_{16} \text{O}_{4} \text{Na} \) by the sodium adduct ion peak at \( m/z \) 247.0937 [M + Na\(^+\)] (calcd for 247.0941, \( \text{C}_{14} \text{H}_{16} \text{O}_{4} \text{Na} \)) in HRESIMS analysis. The 1D NMR spectra of compound 2 displayed signals of two overlapped methyl singlets, two methylens, four methines (three olefinic, one was oxygenated), and four quaternary carbons (one carbonyl, one olefinic) (Tables 1 and 2).
these data exhibit similarities to those of vibralactone [8]. However, the presence of two trans-double bond protons ($\delta_H 5.88$, $J = 16.0$ Hz, H-8; $\delta_H 5.99$, $J = 16.0$ Hz, H-9), and the HMBC correlations from H-9 to Me-11/Me-12 ($\delta_C 30.1$), C-10 ($\delta_C 76.4$), and from H-8 to C-1 ($\delta_C 70.2$), C-7 ($\delta_C 172.5$), and C-2 ($\delta_C 121.2$) suggested that the C9-C10 double bond in vibralactone shifted to the position C8–C9, while C-10 was substituted by a hydroxy in $2^2$ (Fig. 2). This assignment was consistent with the HRESIMS result. The relative configuration of compound $2$ was determined as $1R^*,5S^*$ via ROESY correlations between H-5 ($\delta_H 4.99$) and H-8 ($\delta_H 5.88$) (Fig. 3), and the absolute configuration was assigned as $1R,5S$ by comparison of the specific optical rotation value with those of vibralactone ($[\alpha]_D^{25}-61.3$ for $2$, $[\alpha]_D^{26}-135.1$ for vibralactone). Thus, compound $2$ was elucidated as shown in Fig. 1, and was given the trivial name vibralactone T.

The $^{13}$C NMR and DEPT spectra (Tables 1 and 2) of the colorless oil compound $3$ exhibited signals ascribable to three methyls, three methylenes, four methines, and five quaternary carbons (two carbonyls). These data show high resemblance to those of vibralactone [8]. Compared to vibralactone, the additional three carbons at $\delta_C 176.0$ (C-1'), 68.0 (C-2'), 20.8 (C-3') and corresponding protons at $\delta_H 1.39$ (d, $J = 6.9$ Hz, H-3'), 4.31 (q, $J = 6.9$ Hz, H-2') as well as the HMBC correlations from H-3' to C-2' and C-3' indicated the presence of a lactyl moiety in $3$. The lactyl moiety attached at the oxygen atom at C-13 by the key HMBC correlation from H-13 ($\delta_H 4.74$, 4.79) to C-1'. This assignment agreed with the HRESIMS result which gave a sodium adduct ion peak at $m/z$ 303.1206 [M + Na]$^+$ (calcd for 303.1203, C$_{14}$H$_{20}$O$_5$Na). The absolute configuration of the vibralactone part was determined as $1R,5S$ via biogenetic consideration and evident ROESY correlations between H-5/H-8. However, attempt to settle the absolute configuration of chiral center C-2' of the lactyl moiety by Mosher's method failed. With (R)-MTPA derivative of $3$ in hand, while the counterpart (S)-MTPA derivative was missing because of the insufficient quantity of compound $3$. Therefore, compound $3$ was identified as 13-O-lactyl-vibralactone (Fig. 1).

Compound $4$ was isolated as colorless oil. The 1D NMR data (Tables 1 and 2) displayed high similarities to those of vibralactone G [9], a $\gamma$-lactone derivative obtained from the same fungus but from different batches of cultures. Analysis of the 2D NMR spectra suggested that the 10-OH of vibralactone G was acetylated to give compound $4$, which supported by the HMBC correlation from H-10 ($\delta_H 4.43$) and H-2' ($\delta_H 2.01$) to the carbonyl C-1' ($\delta_C 170.8$). The relative configuration of compound $4$ was proved to be...
same with that of vibralactone G according to the ROESY correlations between H-3 (δH 2.79) and Me-6 (δH 1.32). Thus, compound 4 was identified as 10-O-acetyl vibralactone G (Fig. 1).

Compounds 5 and 6 were purified as white powder. HREIMS analyses suggested that these two compounds had the same molecular formula of C14H18O3. The close NMR data (Tables 1 and 2) of these two compounds which showed resemblance to those of vibranether revealed that compounds 5 and 6 possessed same planar structure and were analogues of vibranether [10]. The absence of the methoxy signal in 1H NMR spectra of compounds 5 and 6

Table 1 ¹H NMR spectroscopic data for compounds 1–6 (600 MHz)

| No. | ¹a          | ¹b          | ²a          | ³c          | ⁴a          | ⁵c          | ⁶a          |
|-----|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1   | 2.34, m     | 2.30, m     |             |             |             |             |             |
| 2   | 1.65, ddd (13.6, 11.0, 5.4) | 1.56, ddd (13.6, 10.7, 5.3) | 5.64, s     | 5.68, s     |             |             |             |
|     | 1.81, ddd (13.6, 4.6, 4.3) | 1.70, overlapped |             |             |             |             |             |
| 3   | 2.71, m     | 2.61, m     |             |             |             |             |             |
| 4   | 2.14, m     | 2.08, m     | 2.66, d (18.7) | 2.72, d (19.0) | 2.12, ddd (12.8, 7.7, 7.7) |             |             |
|     | 1.82, m     | 1.73, m     | 2.87, dd (18.7, 5.7) | 2.83, dd (19.0, 6.0) |             |             |             |
|     |             |             |             |             |             |             | 2.04, overlapped |
| 5   | 3.84, dd (13.8, 13.8, 5.8) | 3.74, ddd (8.2, 8.1, 6.1) | 4.99, d (5.7) | 4.89, d (6.0) |             |             |             |
|     | 3.69, br. dd (13.8, 7.8) | 3.64, ddd (8.2, 8.1, 6.5) |             |             |             |             |             |
| 6   |             |             |             |             |             |             |             |
| 7   |             |             |             |             |             | 1.32, d (6.4), 3H |             |
|     |             |             |             |             |             | 2.46, m     |             |
|     |             |             |             |             |             | 2.31, m     |             |
|     |             |             |             |             |             | 5.50, t (7.5) |             |
|     |             |             |             |             |             | 6.68, d (8.3) |             |
|     |             |             |             |             |             | 6.66, d (8.2) |             |
| 8   | 2.50, br. ddd (14.3, 5.3, 5.3) | 2.41, m     | 5.88, d (16.0) | 5.43, ddd (15.0, 7.5) |             |             |             |
|     | 2.13, overlapped | 2.05, overlapped |             | 2.61, ddd (15.0, 7.5) |             |             |             |
| 9   | 5.14, br. t (7.3) | 5.10, t (7.3) | 5.99, d (16.0) | 5.17, t (7.5) |             |             |             |
| 10  | 1.60, s, 3H | 1.59, s, 3H | 1.26, s, 3H | 1.66, s, 3H |             |             |             |
| 11  | 1.68, s, 3H | 1.68, s, 3H | 1.26, s, 3H | 1.73, s, 3H |             |             |             |
| 12  | 5.17, d (7.0) | 5.15, d (7.0) | 4.17, ddd (15.6, 6.8) | 4.74, d (13.0) |             |             |             |
|     |             |             | 4.20, dd (15.6, 6.8) | 4.79, d (13.0) |             |             |             |
| 1’  | 3.61, overlapped | 3.31, dd (13.8, 6.6, 6.6) |             |             |             |             |             |
|     | 3.38, m     | 3.41, overlapped |             |             |             |             |             |
| 2’  | 3.61, overlapped, 2H | 3.46, overlapped, 2H |             |             |             |             |             |
|     |             |             | 4.31, q (6.9) | 2.01, s, 3H |             |             |             |
| 3’  | 1.39, d (6.9), 3H |             |             |             |             |             |             |
| 2’-OH | 3.84, overlapped | 4.66, t (5.6) |             |             |             |             |             |
| 11-OH |             |             |             | 4.12, br. s |             |             |             |
| 12-OH |             |             |             | 3.54, br. s |             |             |             |
| 13-OH |             |             |             |             | 4.22, t (6.8) |             |             |

¹Recorded in acetone-d₆
²Recorded in DMSO-d₆
³Recorded in CD₃OD
Table 2 ¹³C NMR Spectroscopic Data for Compounds 1–6 (150 MHz)

| No. | ¹a | ²b | ³c | ⁴a | ⁵c | ⁶a |
|-----|----|----|----|----|----|----|
| 1   | 38.3, CH | 36.9 | 70.2, C | 76.8, C |
| 2   | 28.9, CH₂ | 27.7 | 121.2, CH | 126.4, CH | 178.7, C | 77.3, C | 76.6, C |
| 3   | 35.0, CH | 33.7 | 149.5, C | 143.3, C | 39.7, CH | 132.1, CH | 131.5, CH |
| 4   | 30.8, CH₂ | 29.6 | 37.8, CH₂ | 38.7, CH₂ | 34.8, CH₂ | 123.4, CH | 123.2, CH |
| 4a  | 122.4, C | 122.4, C |
| 5   | 65.7, CH₂ | 64.7 | 81.2, CH | 80.0, CH | 75.4, CH | 126.2, CH | 125.7, CH |
| 6   | 21.3, CH₃ | 135.6, C | 135.9, C |
| 7   | 173.8, C | 172.2 | 172.5, C | 174.6, C | 29.0, CH₂ | 128.9, CH | 128.3, CH |
| 8   | 29.8, CH₂ | 28.9 | 119.4, CH | 28.5, CH₂ | 125.6, CH | 116.9, CH | 116.1, CH |
| 8a  | 153.8, C | 152.8, C |
| 9   | 123.2, CH | 122.2 | 143.2, CH | 118.8, CH | 133.9, C | 28.1, CH₃ | 28.1, CH₃ |
| 10  | 133.5, C | 132.5 | 76.4, C | 137.2, C | 69.8, CH₂ | 28.2, CH₃ | 28.1, CH₃ |
| 11  | 17.9, CH₄ | 17.8 | 30.2, CH₃ | 18.2, CH₃ | 14.1, CH₃ | 79.9, CH | 77.9, CH |
| 12  | 26.0, CH₃ | 25.7 | 30.2, CH₃ | 26.1, CH₃ | 72.8, CH | 71.9, CH |
| 13  | 91.6, CH | 90.0 | 61.1, CH₂ | 63.5, CH₂ | 19.2, CH₃ | 18.2, CH₃ |
| 1'  | 49.7, CH₂ | 47.3 | 176.0, C | 170.8, C |
| 2'  | 61.5, CH₂ | 58.7 | 68.0, CH | 20.8, CH₃ |
| 3'  | 20.8, CH₃ |

*aRecorded in acetone-d₆.
*bRecorded in DMSO-d₆.
*cRecorded in CD₃OD.

Fig. 2 Selected ¹H–¹H COSY and HMBC correlations of compounds 1–6.
compared to that of vibranether enabled the establishment of planar structure of these two compounds as chromene vicinal diol derivatives (Fig. 1). The remarkable differences of chemical shifts at the position C-11, C-12, and C-13 though recorded in different NMR solvents suggested that these two compounds were C-11/C-12 diastereomers. Compounds 5 and 6 were determined as threo and erythro configurations by the coupling constants between H-11 and H-12 ($J = 4.0$ Hz for 5; $J = 7.2$ Hz for 6) as well as the chemical shifts of 13-methyls [15, 16]. The absolute configuration of the 11,12-diol moieties of compounds 5 and 6 were assigned using the in situ dimolybdenum CD method developed by Snatzke and Frelek [17, 18]. When adding dimolybdenum tetraacetate [$\text{Mo}_2(\text{OAc})_4$] to solution of 5 and 6 in DMSO, respectively, metal complexes were generated as an auxiliary chromophore. The Cottonogenic diol derivatives are constrained into a chiral, gauche arrangement with the bulkier substituents adopt a pseudo-equatorial position pointing away from the remaining portion of the complex. The signs of band II (310 nm) are same with the O–C–C–O dihedral angle, and are most safely related to the absolute configuration of the diol. As shown in Fig. 4, the positive and negative Cotton effects at 310 nm of compounds 5 and 6 metal complexes corresponding to the clockwise and counter-clockwise of the O–C–C–O dihedral angles, respectively, which led to the unambiguously assign of the absolute configurations of 5 and 6 as 11R,12R and 11S,12R, respectively [19, 20]. Therefore, compounds 5 and 6 were elucidated as shown in Fig. 1 and were given the respective names (11R,12R)- and (11S,12R)-vibradiol.

The previously described compound vibralactone B (7) possessing an epoxy ring at C2–C3 was re-encountered in this research with a yield of more than 3 g [6]. Re-examined of the ROESY spectrum suggested that the mis-assignment of configuration of the epoxy ring as supported by the obvious ROESY correlations between H-8/H-2, and H-2/H-13 (Fig. 5), suggestive of $\alpha$ configuration instead of $\beta$ configuration of the epoxy ring. Finally, crystals of 7 suitable for single crystal X-ray diffraction analysis were cultured via slowly evaporated methanol. As shown in Fig. 5, the X-ray diffraction result unequivocally determined the epoxy ring as $\alpha$ configuration.

In conclusion, six previously undescribed compounds were isolated from the scale-up fermentation of the fungus B. vibrans. All these compounds are biosynthetically related. Vibralactamide A (1) represents the other type of nitrogen-containing vibralactone derivative possible originated from different nitrogen atom-introducing pathway comparing with those of vibralactoximes A–P. This work provided further evidences for divergent vibralactone biosynthesis pathway and expanded the structural diversity of vibralactone-related compounds.

**Scheme 1** Proposed biosynthetic pathway for compound 1
3 Experimental Section

3.1 General Experimental Procedures

Optical rotations were obtained on a JASCO P-1020 digital polarimeter (Horiba, Kyoto, Japan). UV spectra were recorded on a Shimadzu UV-2401PC UV–visible recording spectrophotometer (Shimadzu, Kyoto, Japan). 1D and 2D NMR spectra were obtained on a Bruker Avance III 600 MHz spectrometer (Bruker Corporation, Karlsruhe, Germany). HRESIMS were recorded on an Agilent 6200 Q-TOF MS system (Agilent Technologies, Santa Clara, CA, USA). HREIMS were obtained on a Waters Autospec Premier P776 mass spectrometer. Single crystal X-ray diffraction was performed on an APEX II DUO spectrophotometer (Bruker AXS GmbH, Karlsruhe, Germany). Sephadex LH-20 (Amersham Biosciences, Uppsala, Sweden) and silica gel (Qingdao Haiyang Chemical Co., Ltd) were used for column chromatography (CC). Medium pressure liquid chromatography (MPLC) was performed on a Büchi Sepacore System equipped with pump manager C-615, pump modules C-605 and fraction collector C-660.

Fig. 4 Fischer projections of compounds 5 and 6; Newman projections of the possible conformers 5a, 5b, 5c for 5, and 6a, 6b, 6c for 6; and CD spectra of in situ formed Mo-complexes of 5 and 6 in DMSO after 0.5 h from dissolving in the 1:1.2 ligand-to-metal ratio (green lines marked the position of 310 nm).

Fig. 5 a Structure revision of vibralactone B (7); b ORTEP drawing of compound 7.
(Büchi Labortechnik AG, Flawil, Switzerland), and columns packed with Chromatorex C-18 (40–75 μm, Fuji Silysa Chemical Ltd., Kasugai, Japan). Preparative high performance liquid chromatography (prep-HPLC) were performed on an Agilent 1260 liquid chromatography system equipped with Zorbax SB–C18 column (particle size 5 μm, dimension 9.4 mm × 150 mm, flow rate 8 mL/min, respectively) and a DAD detector (Agilent Technologies, Santa Clara, CA, USA).

3.2 Fungal Material and Cultivation

The fungus *B. vibrans* was collected from the Ailaos Mountains of Yunnan Province, P. R. China in August 2005, and identified by Prof. Mu Zang (Kunming Institute of Botany, CAS), who is a mushroom specialist. A voucher specimen of *B. vibrans* was deposited in the Herbarium of KIB. The culture medium to ferment this fungus consist of MSB. The culture medium were inoculated with *B. vibrans* and 150 rpm for 25 days in dark environment.

3.3 Extraction and Isolation

The culture broth (175 L) of *B. vibrans* was filtered. The filtrate was concentrated under pressure to 10 L and then partition with EtOAc for four times to give a filtrate-originated EtOAc layer (170 g). Meanwhile, the mycelia were extracted by EtOH (95%) for three times. The extraction filtrate was concentrated under pressure to 10 L and then dissolve in water and partition with EtOAc for 3443, 2974, 2926, 1637, 1383, 1126, 1044 cm⁻¹. ¹H NMR (600 MHz, acetone-d₆) and ¹³C NMR (150 MHz, acetone-d₆) data, see Tables 1 and 2; HREIMS m/z 253.1672 [M⁺] (cald for 253.1678, C₁₄H₁₉O₃N).

**Vibractamide A (1)** colorless oil; [α]₂⁰⁰ +4.2 (c 0.11, MeOH); UV (MeOH) λ_max (log ε) 204.5 (4.80); IR (KBr) ν_max 3447, 2975, 2972, 1637, 1383, 1126, 1044 cm⁻¹; ¹H NMR (600 MHz, acetone-d₆ or DMSO-d₆) and ¹³C NMR (150 MHz, acetone-d₆ or DMSO-d₆) data, see Tables 1 and 2; HREIMS m/z 253.1672 [M⁺] (cald for 253.1678, C₁₄H₁₉O₃N).

**Vibractone T (2)** colorless oil; [α]₂⁰⁰ -61.3 (c 0.08, MeOH); UV (MeOH) λ_max (log ε) 204.5 (3.53); IR (KBr) ν_max 3423, 2972, 2927, 2863, 1816, 1722, 1630, 1379, 1122, 977 cm⁻¹; ¹H NMR (600 MHz, CD₂OD) and ¹³C NMR (150 MHz, CD₂OD) data, see Tables 1 and 2; HREIMS m/z 247.0937 [M + Na⁺] (cald for 247.0941, C₁₂H₁₆O₃Na).

**13-O-Lactyl vibralactone (3)** colorless oil; [α]₂⁰⁰ -100.8 (c 0.08, MeOH); UV (MeOH) λ_max (log ε) 203.6 (3.71), 217.0 (sh, 3.50); IR (KBr) ν_max 3427, 2971, 2927, 2858, 1819, 1738, 1631, 1213, 1131, 1035 cm⁻¹; ¹H NMR (600 MHz, CD₂OD) and ¹³C NMR (150 MHz, CD₂OD) data, see Tables 1 and 2; HREIMS m/z 303.1206 [M + Na⁺] (cald for 303.1203, C₁₃H₁₆O₄Na).

**10-O-Acetyl vibralactone G (4)** colorless oil; [α]₂⁰⁰ -10.6 (c 0.18, MeOH); UV (MeOH) λ_max (log ε) 206.0 (3.01), 257.0 (sh, 2.53); IR (KBr) ν_max 3426, 2973, 2930, 2858, 1746, 1632, 1245, 1044 cm⁻¹; ¹H NMR (600 MHz, acetone-d₆) and ¹³C NMR (150 MHz, acetone-d₆) data, see Tables 1 and 2; HREIMS m/z 249.1100 [M + Na⁺] (cald for 249.1097, C₁₂H₁₄O₄Na).

**Vibradiol (5)** white powder; [α]₂⁰⁰ +9.3 (c 0.15, MeOH); UV (MeOH) λ_max (log ε) 196.5 (4.07), 223.0 (4.51), 264.5 (3.55), 311.5 (3.42); IR (KBr) ν_max 3449, 2977, 2925, 1637, 1384, 1262, 1126 cm⁻¹; ¹H NMR (600 MHz, acetone-d₆) and ¹³C NMR (150 MHz, acetone-d₆) data, see Tables 1 and 2; HREIMS m/z 234.1264 [M⁺] (cald for 234.1256, C₁₃H₁₄O₃).

**11S,12R-Vibradiol (6)** white powder; [α]₂⁰⁰ +52.4 (c 0.15, MeOH); UV (MeOH) λ_max (log ε) 222.5 (4.45), 264.5 (3.48), 310.5 (3.35); IR (KBr) ν_max 3443, 2974, 2926, 2857, 1634, 1383, 1125, 1037 cm⁻¹; ¹H NMR (600 MHz, CD₂OD) and ¹³C NMR (150 MHz, CD₂OD) data, see Tables 1 and 2; HREIMS m/z 234.1255 [M⁺] (cald for 234.1256, C₁₃H₁₄O₃).

Single crystal X-ray diffraction data for vibralactone B (7, MeOH) Crystal data for Cu₇⁻0 m: C₇₂H₁₆O₇, M = 224.25, a = 10.0771(4) Å, b = 5.8671(2) Å, c = 10.3263(4) Å, α = 90°, β = 115.1150(10)°, γ = 90°, V = 552.80(4) Å³, T = 100(2) K, space group P2₁, Z = 2, μ(CuKα) = 0.834 mm⁻¹, 5458 reflections measured, 1862 independent reflections (Rint = 0.0365). The final R₁ values were 0.0353 (I > 2σ(I)). The final wR(F²) values were 0.0961 (I > 2σ(I)). The final R₁ values were 0.0354 (all
data). The final $wR(F^2)$ values were 0.0963 (all data). The goodness of fit on $F^2$ was 1.113. Flack parameter $= 0.07(6)$. Crystallographic data for compound 7 have been deposited to the Cambridge Crystallographic Data Center (No. CCDC 1580061). These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html.

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Compliance with Ethical Standards

Conflict of interest The authors declare no competing financial interest.

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