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Oxyindolophyrin: A Novel Fluoride Receptor Derived from N-Confused Corrole Isomer

Hiroyuki Furuta,[*,†,‡] Hiromitsu Maeda,[‡] and Atsuhiro Osuka[*,‡]

PRESTO, Japan Science and Technology Corporation
Department of Chemistry
Graduate School of Science
Kyoto University, Kyoto 606-8502, Japan

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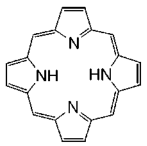
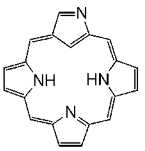
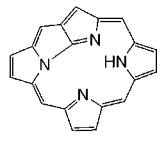
Porphyrin (**1**) and corrole (**4**), representative conjugated tetrapyrrolic macrocycles, are well characterized by the arrangement of all inward-pointing nitrogens in the core. Good stability related to their symmetrical structures is advantageous for a variety of applications such as functional dyes and metal complexing agents.[1] On the other hand, most of their isomers, both known and postulated, have been shown to be less stable than the parent macrocycles by DFT calculations.[2] However, such lower stability might be used to trigger subsequent transformation into novel porphyrinoids. In fact, the *confused* porphyrin isomer (NCP, **2**),[3] possessing the linkages at both the α- and β-positions of one of the pyrroles, has been shown to convert to N-fused porphyrin (NFP, **3**).[4] In this context, incorporation of *confusion,* that is α-, β-linkages, in the corrole framework would be of interest. Herein, we describe the synthesis of the first *confused* corrole isomer, “corrorin (**5**)”, and its transformation into an *oxy-* derivative of “indolophyrin (**6**)”.[5] Both of the compounds are novel and, especially, the latter “oxyindolophyrin” is a new type of anion receptor that shows the remarkable affinity and selectivity to F$^-$.



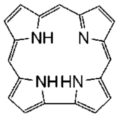
porphyrin (**1**)



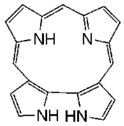
NCP (**2**)



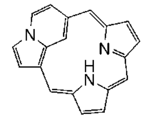
NFP (**3**)



corrole (**4**)



"corrorin (**5**)"



"indolophyrin (**6**)"

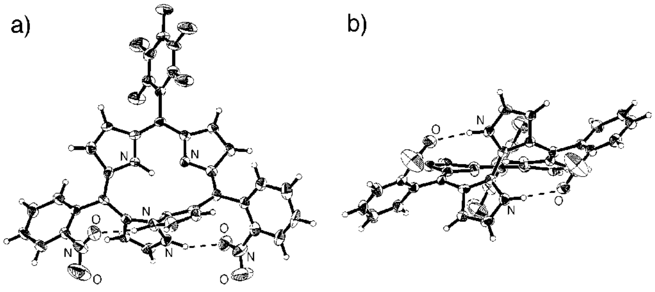
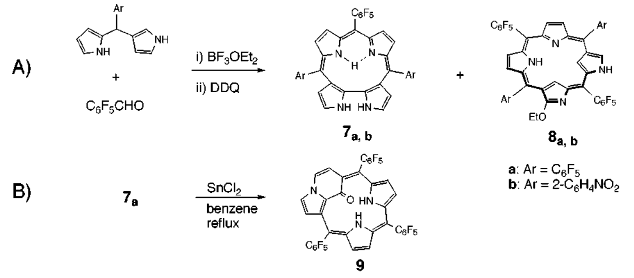


Figure 1. X-ray crystal structures of **7b**, (a) top view and (b) side view.

Scheme 1



The *meso*-aryl derivative of corrole isomer **7a** was obtained as a major product (∼13%) from the acid-catalyzed condensation of N-confused dipyrromethane and pentafluorobenzaldehyde along with doubly N-confused porphyrin (N$_2$CP, **8a**) (Scheme 1A).[6] Corrorin (**7**) was the only bipyrrole-coupling product separated, and no other corrole isomers were obtained. The single-crystal X-ray analysis of related *o*-nitrophenyl derivative (**7b**) revealed the nonplanar structure of a 13-membered ring wherein two pyrrolic rings of the bipyrrole were distorted with a dihedral angle of 59.18° and canted to the dipyrromethene plane at 45.32 and 48.20°, respectively (Figure 1).[7] The nitric oxygens and pyrrolic hydrogens were located within hydrogen-bonding interactions, O•••H−N: 2.915 and 2.950 Å.

The ^{1}H NMR signal of the inner NH in **7a** appeared at 15.53 ppm due to a strong hydrogen-bonding interaction, whereas the outer NH signal was observed at 8.43 ppm as a broad singlet in CDCl$_3$. The inner NH was rapidly exchanging between the nitrogens even at −55 °C as judged from the C_2 symmetric spectra. Due to the twisted bipyrrole moiety, the planar conjugation of a 14 π-electron circuit was hampered, yielding the nonaromatic character of **7a**. In fact, the peripheral CH signals were recorded in the range of 6.9−5.9 ppm. The observed optical absorption bands were broad and relatively weak, reflecting the distorted structure of nonaromatic **7a**.[8]

Corrorin **7a** was stable in the air but was found to transform into a new macrocycle, oxyindolophyrin (**9**), by treatment with SnCl$_2$.[9] When a benzene solution of **7a** was refluxed for 8 h with 5 equiv of SnCl$_2$, a violet-colored product **9** was obtained in 6% yield (Scheme 1B). The single-crystal structure of **9** showed the presence of an oxo-substituted indolizine moiety and dipyrromethene unit in the skeleton (Figure 2).[10] The macrocyclic core was slightly bent, that is two pyrrole and indolizine rings were tilted up (+15.99°), down (−13.27°), and down (−19.51°) from the mean plane of 22-atom core, respectively.[11]

[†] PRESTO, Japan Science and Technology Corporation.

[‡] Kyoto University.

(1) (a) *The Porphyrin Handbook*; Kadish, K. M., Smith, K. M., Guilard, R., Eds; Academic Press: San Diego, 1999; Vol. 6. (b) Sessler, J. L.; Weghorn, S. J. *Expanded, Contracted, and Isomeric Porphyrins*; Elsevier: Oxford, 1997; pp 520.

(2) The only exception is (2.0.2.0)-porphyrin isomer, porphycene. (a) Wu, Y.-D.; Chan, K. W. K.; Yip, C.-P.; Vogel, E.; Plattner, D. A.; Houk, K. N. *J. Org. Chem.* **1997**, *62*, 9240−9250. (b) Vogel, E.; Binsack B.; Hellwig, Y.; Erben, C.; Heger, A.; Lex, J.; Wu, Y.-D. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 2612−2615. (c) Szterenberg, L.; Latos-Grazynski, L. *Inorg. Chem.* **1997**, *36*, 6287−6291.

(3) (a) Furuta, H.; Asano, T.; Ogawa, T. *J. Am. Chem. Soc.* **1994**, *116*, 767−768. (b) Chmielewski, P. J.; Latos-Grażyński, K.; Rachlewicz, T.; Głowiak, T. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 779−781.

(4) Furuta, H.; Ishizuka, T.; Osuka, A.; Ogawa, T. *J. Am. Chem. Soc.* **2000**, *122*, 5748−5757.

(5) We have put trivial names *corrorin* for confused corrole isomers and *indolophyrin* for porphyrinoids containing a mono-aza-indene moiety, both of which consist of a 13-membered ring.

(6) Furuta, H.; Maeda, H.; Osuka, A. *J. Am. Chem. Soc.* **2000**, *122*, 803−807.

(7) Crystal data for **7b**: $C_{37}H_{19}N_6F_5O_4 \cdot CHCl_3 \cdot H_2O$, $M_w = 843.99$, monoclinic $C2/c$ (No. 15), $a = 28.462(1)$ Å, $b = 15.0723(6)$ Å, $c = 18.036(1)$ Å, $\beta = 106.388(2)°$, $V = 7422.8(6)$ Å^3, $Z = 8$, $D_{calcd} = 1.511$ g/cm^3, $T = 296$ K, $R = 0.104$, $R_w = 0.113$, GOF $= 0.76$ for 2369 reflections with $I > 3.0\sigma(I)$.

(8) See Supporting Information.

(9) Other Lewis acids such as TiCl$_4$ and AlCl$_3$ gave unidentified products.

(10) Crystal data for **9**: $C_{37}H_{10}N_3F_{15}O \cdot 0.7C_7H_8 \cdot 0.25C_7H_{16}$, $M_w = 887.04$, monoclinic $C2/c$ (No. 15), $a = 43.523(1)$ Å, $b = 11.9032(3)$ Å, $c = 31.6614(8)$ Å, $\beta = 116.991(1)°$, $V = 14616.0(7)$ Å^3, $Z = 16$, $D_{calcd} = 1.612$ g/cm^3, $T = 123$ K, $R = 0.069$, $R_w = 0.219$ (all data), GOF $= 1.06$ for 9744 reflections with $I > 2.0\sigma(I)$.

(11) In the data crystal, two independent structures of **9** were found. The other **9** gave the values of +14.71, −14.98, and −20.46°, respectively.

10.1021/ja015892x CCC: $20.00

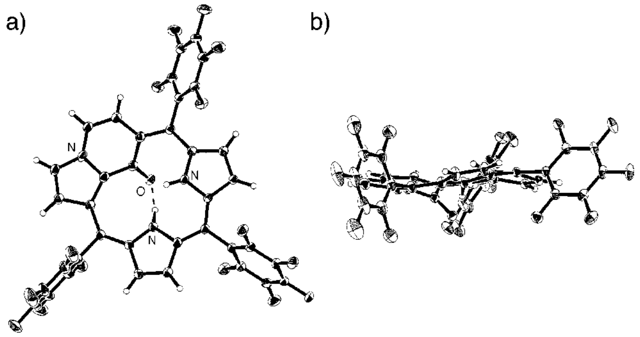
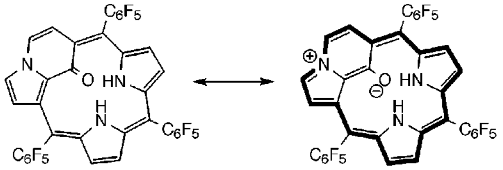


Figure 2. X-ray crystal structures of **9**, (a) top view and (b) side view.

Scheme 2. Resonance Forms of Oxyindolophyrin, **9**



The ^{1}H NMR spectrum of **9** showed the peripheral CH signals at 8.8−7.8 ppm and two inner NH protons at −1.67 ppm in $CDCl_3$ at room temperature. The NH signal further split into two resonances (−3.79 and +0.17 ppm) at −70 °C, probably due to the observed hydrogen-bonding interaction between C═O and co-facial NH. The ring current effect observed infers that **9** has aromatic character presumably due to the contribution of a zwitterionic canonical form that has an 18 π-electron circuit (Scheme 2).[12] Supporting this, the absorption spectrum of **9** was similar to that of [18]-porphyrin, namely, the intense Soret band at 425.0 nm and Q-like bands at 502.5 and 558.5 nm were observed in $CHCl_3$. Furthermore, an intermediate value C═O bond distance of 1.32 Å,[13] between typical C═O (1.20 Å) and C−O (1.41 Å),[14] relatively upfield-shifted ^{13}C NMR signal at 166.06 ppm compared with normal C═O, and a weak C═O IR stretching at 1650 cm^{-1}, all of these data indicated a zwitterionic character in **9**.

Reflecting the rigid narrow and 13-membered ring structure of **9**, the canted oxyindolidine moiety was forced on one side and, consequently, afforded two optical isomers that showed the distinct circular dichroism (CD) at 281, 318, 365, 429, and 443 nm.[15] These isomers were stable, and the racemization could not be detected by chiral HPLC even after heating in DMSO at 150 °C over 2 days. The oxy-group might be introduced from an adventitious water molecule in the eluent used for silica gel column chromatography.[16]

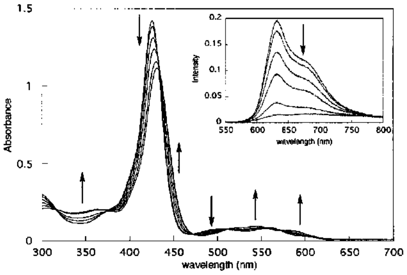


Figure 3. UV/vis absorption and emission (inset) spectral changes of **9** upon addition of Bu_4NF in $CHCl_3$. [**9**]: 1.45 × 10^{-5}M, [Bu_4NF]: 0, 1, 3, 5, 10, 30 equiv. Arrows indicate the order of [Bu_4NF] added.

One of the interesting properties of **9** was its capability of binding fluoride anion using hydrogen-bonding interactions with the inner pyrrolic NH. In Figure 3, the absorption and emission spectral changes upon addition of Bu_4NF in $CHCl_3$ are shown. The Soret band at 425 nm was shifted to 431 nm, and the emission band at 631 nm was suppressed progressively by increasing the amounts of Bu_4NF added. In a preliminary study, the binding isotherm was analyzed by assuming 1:1 stoichiometry,[17] and the association constant K, 1.4 × 10^4 M^{-1}, obtained from the emission spectral change at 25 °C, seems comparable to that of reported F$^-$ receptor, calix[4]pyrrole (∼1.7 × 10^4 M^{-1} in CH_2Cl_2).[18] In fact, the competition experiments using ca. 1.0 × 10^{-5} M of each macrocycle in the presence of equimolar Bu_4NF showed only 40% inhibition. Moreover, the anion-binding property of **9** is specific for F$^-$, and other halide anions, Cl$^-$, Br$^-$, and I$^-$, did not cause any spectral change at all. The fluorescent nature of the receptor **9** would be attractive for F$^-$ anion sensing.[19]

In summary, we have shown here the new entities of *corrorin* and its rearranged derivative, *oxyindolophyrin*, both of which displayed unique chemical properties. The formation mechanisms of these compounds are not clear at this moment, but at least it can be said safely, the reactivity of the α-position of *confused* pyrroles played an important role for such transformation.[20] Incorporation of *confusion* in oligopyrrolic macrocycles, therefore, can be interpreted, in some sense, to *activate macrocycles for further mutation*. "Confusion approach" to porphyrinoids is continuously underway.

Acknowledgment. We thank Dr. Mikio Yasutake (Kyushu University) for help with the X-ray structural work for **9** and Professor Yuichi Ishikawa (Oita University) for CD spectra measurements.

Supporting Information Available: Synthetic procedures, spectral data of **7a,b** and **9**, absorption spectrum of **7a**, CD spectra of **9**, DFT calculations on corrole isomers, F$^-$ binding plots, and crystallographic data for **7b** and **9** (PDF). This material is available free of charge via Internet at http://pubs.acs.org.

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(12) Lash, T. D. *Synlett* **2000**, 279−295.

(13) Interestingly, the other structure of **9** in the crystal shows the value of 1.23 Å. We are now investigating the interaction of the solvent molecule in the crystal.

(14) March, J. *Advanced Organic Chemistry*, 3rd ed.; Wiley: New York, 1985; p 19.

(15) See Supporting Information.

(16) Addition of small amounts of $H_2{}^{18}O$ in the reaction mixture did not produce the ^{18}O-labeled **9**, which was interpreted as that the hydrolysis took place during the silica gel column chromatography.

(17) The actual binding isotherm displayed a sigmoidal shape, suggesting the equilibrium involving 2:1, 1:1, and 1:2 complexes. The detail binding study using ^{19}F NMR is in progress.

(18) Gale, P. A.; Sessler, J. L.; Král, V.; Lynch, V. *J. Am. Chem. Soc.* **1996**, *118*, 5140−5141.

(19) Beer, P. D.; Gale, P. A. *Angew. Chem., Int. Ed.* **2001**, *40*, 486-516.

(20) DFT calculations at the B3LYP/6-31G** level were performed on the skeletons of corroles and corrorins. The optimized energy of **4** is the most stable at 37-43 kcal/mol compared to those of **5** and other corrole isomers. See Supporting Information.