

## 科学研究費助成事業 研究成果報告書

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研究課題名(和文) Strategic Exploration of Quinoline-Based Materials

研究課題名(英文) Strategic Exploration of Quinoline-Based Materials

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研究成果の概要(和文)：本研究はキノリンを単位ユニットに用いる環状4量体TEQをデザイン・合成した。16員環骨格を持つTEQはポルフィリンと同様のN4型大環状分子であり、サドル形状が特徴的である。TEQはS4対称性の分子だが、置換基の導入によりC2対称性となりキラリティーを獲得し、剛直な構造であるため240°でもラセミしない特異分子である。TEQは一連の金属錯体を形成することが確認されており、そのFe錯体は低触媒量でベンジルアミンの脱水素反応を促進することも見出している。TEQはプロトン化ならびにZn(II)カチオンの存在下に強蛍光性を獲得し、構造的に堅牢な垂鉛のプロープとしての有用性が期待される。

研究成果の学術的意義や社会的意義

The cyclic quinoline tetramer TEQ is a novel nitrogen ligand that can be regarded as a non-planar porphyrinoid. It coordinates with a range of transition metals, showing great potential in catalysis, including asymmetric transformations. Additionally, it shows promise as a fluorescent material.

研究成果の概要(英文)：In this study, we designed and synthesized a cyclic quinoline tetramer, TEtraQuinoline (TEQ), which features a 16-membered ring skeleton. TEQ is an N4-type macrocyclic molecule similar to porphyrin, but it is characterized by its saddle-shaped structure and neutral nature when acting as a ligand. TEQ forms complexes with a series of transition metals (Fe<sup>2+</sup>, Co<sup>2+</sup>, Ni<sup>2+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup>, and Pd<sup>2+</sup>), as confirmed by X-ray crystallography. A TEQ/Fe(II) complex exhibited high catalytic activity, promoting the dehydrogenation of benzylamine with catalyst amounts as low as 0.1 mol%. TEQ also demonstrated strong fluorescence upon protonation and in the presence of Zn(II) cations, indicating potential applications as structurally robust probes for acids and zinc. Additionally, we synthesized a novel nitrogen macrocyclic ligand, In2Q2, consisting of two indoles (In) and two quinolines (Q). Its saddle-shaped structure and formation of Zn complexes have been confirmed.

研究分野：Structural organic chemistry, Organic synthesis

キーワード：TEtraQuinoline TEQ quinoline In2Q2 macrocyclic compounds

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## 様式 C - 19、F - 19 - 1、Z - 19 (共通)

### 1. 研究開始当初の背景

In recent decades, macrocyclic compounds, such as crown ethers, porphyrinoids and calixarenes, have garnered considerable attention due to their wide-ranging applications in chemistry, biology, and materials science. Consequently, the design and synthesis of new macrocycles remain highly desirable. While there has been significant progress in the development of porphyrinoids with pyrrole subunits, our group is focused on studying macrocycles based on quinolines, a field that has been largely overlooked for a long time.

In 2019, we developed the first member of this family, TriQuinoline (TQ), a cyclic quinoline trimer connected at the 2- and 8-positions. TriQuinoline (TQ) is a planar, 12-membered macrocyclic molecule with a central cavity surrounded by three nitrogens. It exhibits a superbinding ability to  $H^+$ , water solubility (despite a  $CLogP$  of 5.96), supramolecular complexation via  $CH-\pi$  interactions, and DNA intercalation.

### 2. 研究の目的

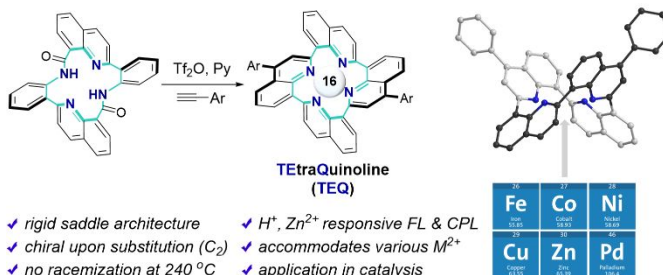
This project aims to design new macrocyclic compounds that will significantly contribute to organometallic chemistry, supramolecular chemistry, and materials science. Given that the quinoline unit has been largely neglected as a fundamental building block for macrocycle construction, we anticipate that incorporating quinoline nitrogens will markedly alter the properties of these macrocycles. This research focuses on the design and synthesis of novel cyclic quinoline oligomers, such as quinoline tetramers (TEtraQuinoline TEQ) and other quinoline-incorporated macrocycles. Additionally, the application of TEQ as ligands, host molecules, and functional materials will be explored.

### 3. 研究の方法

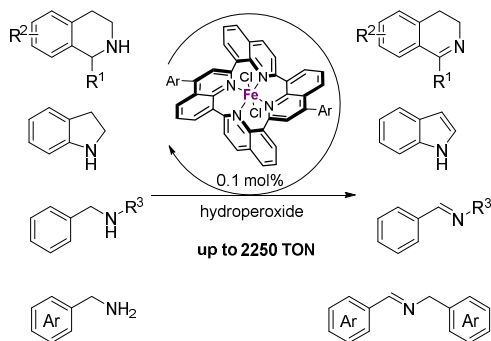
The synthetic routes for quinoline tetramers, such as TEtraQuinoline (TEQ), and other quinoline-containing macrocycles, including a hybrid macrocycle with two indoles and two quinolines (In2Q2), have been developed. TEQ is synthesized from a cyclic dimer of quinoline-formanilide substrate and an alkyne in the presence of  $Tf_2O$  and pyridine derivatives. Density Functional Theory (DFT) calculations were performed to gain a deeper understanding of the reaction mechanism. Due to the  $C_2$ -symmetric structure of TEQ, the energy barrier for flipping was studied. The fluorescent properties of TEQ have also been investigated. Additionally, the synthesis of TEQ/metal complexes was achieved, and their structures were confirmed by X-ray crystallography. The catalytic activity of the TEQ/Fe complex in dehydrogenation reactions was evaluated.

### 4. 研究成果

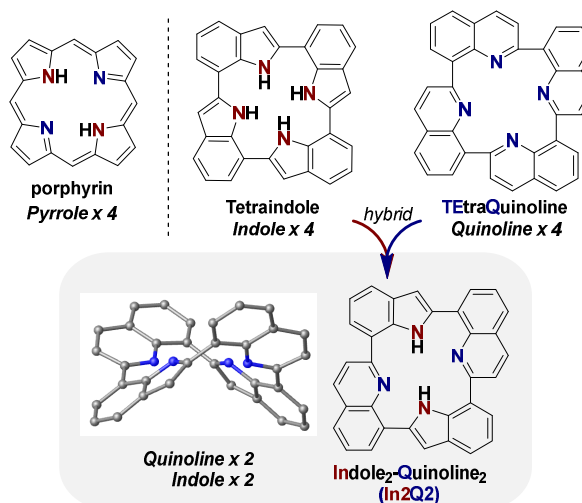
(1) The synthesis of TEtraQuinoline (TEQ) was realized from a cyclic dimer of quinoline-formanilide substrate, in the presence of alkyne,  $Tf_2O$  and pyridine derivatives. TEQ had a rigid saddle-shaped structure that can acquire chirality ( $C_2$  symmetry) through substituents on two of the quinoline rings. Optically pure TEQ was obtained via chiral resolution and had a high flipping energy, resisting racemization even at  $240^\circ C$ , indicating its potential as an asymmetric  $N_4$  ligand. TEQ exhibited intriguing chemical and physical properties, including proton-responsive fluorescence and selective  $Zn^{2+}$ -responsive fluorescence among various transition and group 1 and 2 metal cations. It also demonstrates coordination abilities with several transition metals ( $Fe^{2+}$ ,  $Co^{2+}$ ,  $Ni^{2+}$ ,  $Cu^{2+}$ ,  $Zn^{2+}$ ,  $Pd^{2+}$ ), showing significant potential in organometallic chemistry.



(2) A TEQ-Fe(II) complex displayed catalytic activity in the dehydrogenation of amines to produce imines, with various primary and secondary amine substrates yielding imine products in moderate to good yields and turnover numbers up to 2250. Additionally, chemoselective deprotection of the *N*-Bn group over the *N*-Cbz group was achieved, highlighting the practicality of this methodology as a complementary deprotection protocol to reductive conditions promoted by Pd catalysis.



(3) We also developed a new saddle-shaped tetradentate nitrogen ligand, In2Q2, consisting of two indole (In) and two quinoline (Q) units, showing different properties compared with porphyrin, Tetraindole and TETraQuinoline. In2Q2 had a non-flat saddle-shaped architecture with  $C_2$  symmetry. It can coordinate with  $Zn^{2+}$  to form a neutral Zn complex, acting as a dianionic ligand. The fluorescence of In2Q2 was observed in both the solution phase and solid state, with emission maxima ranging from 456-527 nm depending on different substituents.



#### < 引用文献 >

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## 5. 主な発表論文等

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2. 論文標題 Recent Advances in Quinoline-Based Macrocycles: Synthesis, Properties, and Applications in Catalytic Reactions	5. 発行年 2024年
3. 雑誌名 Synthesis	6. 最初と最後の頁 1765 ~ 1774
掲載論文のDOI (デジタルオブジェクト識別子) 10.1055/s-0042-1751545	査読の有無 有
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〔図書〕 計0件

〔産業財産権〕

〔その他〕

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TEQ was featured by Nature Chemistry  
<https://www.nature.com/articles/s41557-023-01180-7>

6. 研究組織

	氏名 (ローマ字氏名) (研究者番号)	所属研究機関・部局・職 (機関番号)	備考
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7. 科研費を使用して開催した国際研究集会

〔国際研究集会〕 計0件

8. 本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関
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