J. Am. Chem. Soc. **1995,** *117,* 7850−7851

The First Metalloporphyrin Nitrosamine Complex: Bis(diethylnitrosamine)(*meso*-tetraphenylporphyrinato)iron(III) Perchlorate

Geun-Bae Yi, Masood A. Khan, and
George B. Richter-Addo*

Department of Chemistry and Biochemistry
University of Oklahoma, 620 Parrington Oval
Norman, Oklahoma 73019

Received March 15, 1995

Nitrosamines ($R_2NN{=}O$) are ubiquitous in biology and in the environment due to the abundance of nitrogen oxides and amine precursors, and they are generally considered to be carcinogenic.[1] Their chemical reactions continue to be studied in great detail.[2] The amido nitrogen in $R_2\mathit{N}N{=}O$ can be protonated.[3] Furthermore, the oxygen atom in nitrosamines may also be protonated[4] or alkylated[5] or may form adducts with Lewis acids such as BF_3 and PCl_5.[6] Nitrosamines also interact with heme-containing biomolecules such as cytochrome P450, to result in metabolic activation,[7] or with hemoglobin, to form adducts.[8] Furthermore, it has been reported that *N*-(hydroxyethyl)protoporphyrin IX forms in the livers of mice after diethylnitrosamine treatment.[9] Despite their crucial importance, only a handful of metal complexes of nitrosamines are known.[6b,10,11] Also, no structural information was available on the interactions of nitrosamines with heme or metalloporphyrin complexes prior to this study. We are interested in determining how biologically active metal−NO compounds are involved in the *N*-nitrosation of amine groups to generate carcinogenic nitrosamines *in vitro* and *in vivo*. In this Communication, we present our results on the high-yield synthesis and crystallographic characterization of the first nitrosamine complex of a metalloporphyrin.

To a stirred toluene (40 mL) solution of $(TPP)FeOClO_3{\cdot}2THF$ (0.200 g, 0.219 mmol)[12] under an atmosphere of nitrogen was added excess diethylnitrosamine (0.500 mL, 4.65 mmol). The solution was stirred for 10 min, and a reddish-purple microcrystalline solid precipitated out. Hexane (40 mL) was added to complete the precipitation. The supernatant solution was discarded, and the solid dried *in vacuo* to give $[(TPP)Fe(Et_2NNO)_2]^+ClO_4^-$ ($\mathbf{1}^+ClO_4^-$, 0.204 g, 0.210 mmol, 96% yield) as analytically pure dark purple crystals.[13] The infrared spectrum of paramagnetic $\mathbf{1}^+ClO_4^-$ reveals a new strong band at 1270 cm^{-1} (KBr) that is assigned to ν_{NO} of the coordinated diethylnitrosamine, and this assignment was confirmed by analysis of the IR spectrum of the $Et_2N^{15}NO$ analog ($\nu_{^{15}NO}$ = 1253 cm^{-1}; $\Delta\nu$ = 17 cm^{-1}). Free aliphatic nitrosamines display higher ν_{NO}'s in the 1460−1425 cm^{-1} region.[14] The IR spectrum of $\mathbf{1}^+ClO_4^-$ also shows a band at 1107−1069 cm^{-1} (s, br) due to uncoordinated ClO_4^-.[15]

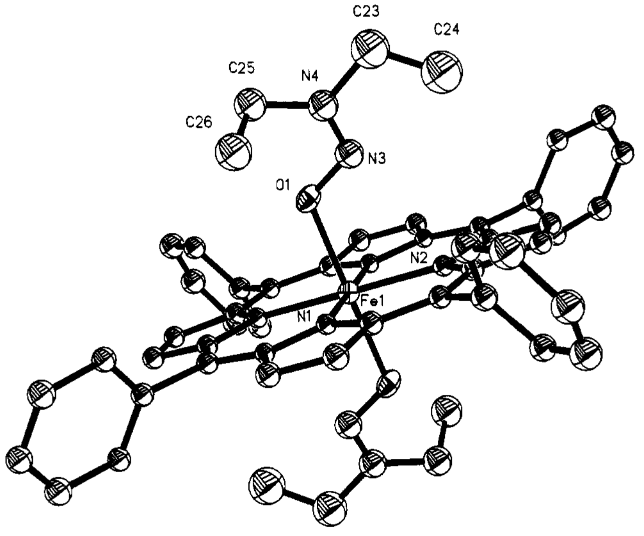

Figure 1. Molecular structure of one of the cations of $[(TPP)Fe(Et_2NNO)_2]^+ClO_4^-$ ($\mathbf{1}^+ClO_4^-$). Hydrogen atoms have been omitted for clarity. Selected bond distances (Å) and angles (deg) for one of the cations in the asymmetric unit: Fe1-N1 = 2.042(6), Fe1-N2 = 2.046(6), Fe1-O1 = 2.107(6), O1-N3 = 1.260(9), N3-N4 = 1.276(10), N4-C25 = 1.442(12), N4-C23 = 1.468(12); Fe1-O1-N3 = 116.3(5), O1-N3-N4 = 113.9(7), N3-N4-C25 = 122.8(8), N3-N4-C23 = 117.0(8), C25-N4-C23 = 120.1(8).

In order to unambiguously determine the mode of linkage of the nitrosamine ligands toward the iron center in $\mathbf{1}^+ClO_4^-$, we subjected a suitable crystal to a single-crystal X-ray crystallographic analysis.[16] The diagram of the cationic portion of the complex is shown in Figure 1. The cation has a crystallographically imposed center of symmetry, with the Fe atom situated at that center of symmetry in the plane of the porphyrin nitrogens. The average Fe−N(porphyrin) bond length

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[11] *N*-bound cyclometallated complexes of Pd and Pt: (a) Albinati, A.; Affolter, S.; Pregosin, P. S. *J. Organomet. Chem.* **1990**, *395*, 231. (b) Constable, A. G.; McDonald, W. S.; Shaw, B. L. *J. Chem. Soc., Dalton Trans.* **1980**, 2282.

[12] (a) TPP = tetraphenylporphyrinato dianion. (b) The complex was prepared from (TPP)FeCl and $AgClO_4{\cdot}H_2O$ in THF in a manner analogous to the preparation of $(TPP)FeOClO_3{\cdot}0.5$toluene: Reed, C. A.; Mashiko, T.; Bentley, S. P.; Kastner, M. E.; Scheidt, W. R.; Spartalian, K.; Lang, G. *J. Am. Chem. Soc.* **1979**, *101*, 2948. Anal. Calcd for $C_{52}H_{44}N_4O_6ClFe$. C, 68.46; H, 4.86; N, 6.14. Found: C, 67.84; H, 4.53; N, 6.37.

[13] (a) Anal. Calcd for $C_{52}H_{48}N_8O_6ClFe$. C, 64.23; H, 4.98; N, 11.52. Found: C, 64.28; H, 5.11; N, 11.36. Low resolution mass spectrum (FAB$^+$) *m/z* 668 $[(TPP)Fe]^+$. μ_{eff} = 4.96. (b) Magnetic moments were measured on 3.1 × 10^{-3} M solutions in C_6D_6 at 21 ± 1° by the Evan's method: Grant, D. H. *J. Chem. Educ.* **1995**, *72*, 39.

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[16] Crystals of $\mathbf{1}^+ClO_4^-$ are monoclinic, $P2_1/a$, a = 13.193 (5) Å, b = 13.479 (3) Å, c = 26.039 (3) Å, β = 94.39 (3)°, V = 4617 (2) Å^3, Z = 4, and d(calcd) = 1.399 g cm^{-3}. The data were collected on an Enraf Nonius CAD-4 diffractometer with Mo Kα radiation (λ = 0.71073 Å) at 183 K. The data were corrected for Lorentz and polarization effects. The structure was solved by direct methods (*SHELXS-86*)[a] and refined by full-matrix least squares on F^2 using all reflections (*SHELXL-93*).[b] The structure was refined to a final conventional R1 = 0.067 (wR2 = 0.172, GOF = 1.1) for 2711 "observed" reflections with $I \geq 2\sigma(I)$. The asymmetric unit contains two independent halves of the cations in special positions and the perchlorate anion in a general position. (a) Sheldrick, G. M. *Acta Crystallogr., Section A* **1990**, *46*, 467. (b) Sheldrick, G. M. *Program for the Solution of Crystal Structures*; University of Göttingen, Germany; 1993.

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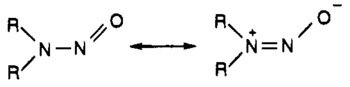
of 2.041(7) Å is indicative of substantial porphyrin core expansion in this six-coordinate complex and is similar to porphyrin core expansions noted for the *high-spin* ferric compounds $[(TPP)Fe(H_2O)_2]^+$ [17] and $[(TPP)Fe((CH_2)_4SO)_2]^+$ [18] (Fe$-$N = 2.045 Å).[19-21]

The most chemically interesting feature of the structure of $\mathbf{1}^+ClO_4^-$ is that the nitrosamine ligands are bound to the formally Fe(III) center in a σ-O fashion. The average N$-$O distance of the bound diethylnitrosamine is 1.273(9) Å, and the average nitrosamine N$-$N bond distance is 1.282(10) Å. To the best of our knowledge, the structure of free diethylnitrosamine has not been reported. However, these values may be compared to related distances in free *dimethyl*nitrosamine of 1.234 (N$-$O) and 1.344 Å (N$-$N) as determined by electron diffraction,[22] and 1.260(6) (N$-$O) and 1.320(6) Å (N$-$N) as determined by low-temperature X-ray diffraction.[23] The amido nitrogens of the bound nitrosamines in $\mathbf{1}^+ClO_4^-$ are not bonded to the iron center, and the nitrosamine functionalities are essentially planar. Thus, the complexed diethylnitrosamine is best represented by a resonance hybrid having a significant contribution from structure **B**. A similar contribution from the dipolar structure **B** (R = Me) is noted in the low-temperature X-ray structure of *dimethyl*nitrosamine.[23]



A **B**

(R = Et)

The $((CH_3)_2NNO)CuCl_2$ compound is the only other metal complex with discrete nitrosamine ligands that has been crystallographically characterized, and the N$-$O and N$-$N distances in this complex are 1.22(2) and 1.29(2) Å, respectively.[10c,24] Although the structure of the Cu complex reveals a dominant nitrosamine$-$metal interaction via the nitroso O atom, the nitroso N atom is also found to interact with the metal. Thus, the structure of $\mathbf{1}^+ClO_4^-$ represents the first unambiguous determination of a sole σ-O binding mode for nitrosamines in metal complexes. Furthermore, complex $\mathbf{1}^+ClO_4^-$ now joins the family of six-coordinate ferric porphyrins containing two axially bound O-donor ligands.[17,18]

In summary, $\mathbf{1}^+ClO_4^-$ is the first nitrosamine complex of iron to be structurally characterized and is also the first nitrosamine metalloporphyrin complex to be reported. Variable temperature magnetic measurements for $\mathbf{1}^+ClO_4^-$, as well as reactions designed for the activation of the bound nitrosamine ligands, are currently in progress.

Acknowledgment. G.B.R.A. is grateful to the University of Oklahoma for startup funds. The research results discussed in this publication were made possible by the OCAST award for project no. HN4-017 from the Oklahoma Center for the Advancement of Science and Technology.

Supporting Information Available: Experimental details for the crystal structure determination and refinement, drawings, and tables of atomic coordinates, anisotropic thermal parameters, bond distances and angles, and torsion angles for $\mathbf{1}^+ClO_4^-$ (20 pages); tables of calculated and observed structure factors for $\mathbf{1}^+ClO_4^-$ (15 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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