Inorganic Chemistry
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Chelating Ligand Conformation Driving the Hypoxanthine Metal Binding Patterns

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Supporting Information

ABSTRACT: The X-ray diffraction structural results of 23 ternary compounds, type M^{II}(iminodiacetate-like)(hypoxanthine) [M = Co, Ni, Cu, or Zn], show that the iminodiacetate moiety conformation (*mer*-NO_2 or *fac*-NO_2) is able to drive the M-hypoxanthine binding patterns displaying the M−N9 or M−N3 bond, cooperating with a N9−H···O intramolecular interaction, respectively.

In the past decade, a large number of papers based on the metal binding patterns of natural nucleobases and closely related ligands have been published.[1,2] As a result, adenine is now considered a fairly versatile ligand able to bind different metal centers in a variety of cationic, neutral, or anionic forms.[2] Furthermore, adenine is currently being used to build a new class of interesting metal−organic frameworks, the so-called MBioFs.[3] However, natural oxopurines are poorly studied. Prior to the present study, the structural information concerning the metal binding patterns of hypoxanthine was limited to a few compounds. Two polymorphs of neutral hypoxanthine (Hhyp) have been reported for the same tautomer H(N9)hyp.[4] In metal complexes, the tautomer H(N9)hyp gives rise to the M−N7 or $M_2(\mu_2$-N3,N7) modes, whereas the tautomer H(N7)hyp displays the mode $M_2(\mu_2$-N3,N9).[5] Hence, these patterns do not show examples in which Hhyp plays unidentate coordination roles by its most basic N9 or less basic N3 donor atoms. In addition, in the CSD database are also reported some structures of the hypoxanthinium(1+) cation, which exhibits M−N3 coordination as the H_2(N7, N9)hyp^+ tautomer, or the hypoxanthinate(1−) anion, which binds the metal center through the bond M−N9 or as the bridging μ_2-N7,N9 mode. Very recently, because of increasing interest on metal complexes with oxopurines, a Cu^{II}MBioF assisted by the unprecedented μ_2-N7,O6−H(N9)hyp role (according to the conventional numbering of purines) has been reported.[6]

This Communication deals with the structures of 22 novel (**1**−**22**) ternary complexes having one M^{II} first-row metal center and iminodiacetate-like (IDA-like) chelators and Hhyp as main coligands. Moreover, the molecular and crystal structure of $[Cu(tda)(Hhyp)(H_2O)]\cdot 2H_2O$ (**23**) is also reported. Besides, four nickel(II) or cobalt(II) binary chelate compounds were also studied (**11b**, **14b**, **17b**, and **18b**).

The binary compounds were obtained by a stoichiometric reaction of the appropriate iminodiacetic acid and basic metal carbonate.[7] The reaction of the chelating agents and the basic metal carbonates yields CO_2 as the main byproduct, which can be easily removed by means of stirring, heating, and moderate vacuum. The syntheses of the ternary compounds were carried out by a stoichiometic reaction between hypoxanthine and a solution of the corresponding metal chelate, prepared following the previously reported procedure.[7] These latter syntheses were prepared in a range of 1−0.5 mmol of reactants in 100 mL of an aqueous solution. In some cases, crystallization of the ternary complexes needs the addition of ethanol to the partially concentrated mother liquors.

The formulas of the ternary compounds are $[Cu(IDA)(Hhyp)(H_2O)]\cdot H_2O$ (**1**), $[Cu(MIDA)(Hhyp)(H_2O)]\cdot H_2O$ (**2**), $[Cu(\mu_2\text{-NBzIDA})(Hhyp)]_n$ (**3**), $[Cu(\mu_2\text{-MEBIDA})(Hhyp)]_n$ (**4**), $[Cu(FBIDA)(Hhyp)(H_2O)]\cdot 1.5H_2O$ (**5**), $\{[Cu(\mu_2\text{-CBIDA})(Hhyp)\cdot Cu(CBIDA)(Hhyp)(H_2O)]_4\cdot 2DEPh\cdot 21H_2O\}_n$ (**6**), $[Cu(pheida)(Hhyp)(H_2O)]\cdot 2H_2O$ (**7**), $[Cu_2(p\text{-XDTA})(Hhyp)_2(H_2O)_2]\cdot 2H_2O$ (**8**), $[Co(NBzIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**9**), $[Co(MEBIDA)(Hhyp)\ (H_2O)_2]\cdot H_2O$ (**10**), $[Co(MOBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**11**), $[Co(FBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**12**), $[Co(CBIDA)(Hhyp)\ (H_2O)_2]\cdot H_2O$ (**13**), $[Ni(NBzIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**14**), $[Ni(MEBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**15**), $[Ni(MOBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**16**), $[Ni(FBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**17**), $[Ni(CBIDA)(Hhyp)(H_2O)_2]\cdot H_2O$ (**18**), $[Cu(pdc)(Hhyp)(H_2O)]$ (**19**), $[Co(pdc)(Hhyp)(H_2O)_2]\cdot H_2O$ (**20**), $[Ni(pdc)(Hhyp)(H_2O)_2]$ (**21**), $[Zn(pdc)(Hhyp)(H_2O)_2]$ (**22**), and $[Cu(tda)(Hhyp)(H_2O)]\cdot 2H_2O$ (**23**). The reported binary compounds agree with the formulas $[Co(MOBIDA)(H_2O)_3]\cdot H_2O$ (**11b**), $[Ni(NBzIDA)(H_2O)_3]$ (**14b**), $[Ni(FBIDA)(H_2O)_3]\cdot H_2O$ (**17b**), and $[Ni(CBIDA)(H_2O)_3]\cdot H_2O$ (**18b**).

The ternary copper(II) compounds from **1** to **8** exhibit a distorted square-pyramidal-based coordination, type 4 + 1. The four basal donor atoms are N9(Hhyp) and the three donors of the iminodiacetate moiety in *mer*-NO_2 conformation (Figure 1, top). The referred compounds are mostly molecular, except for the polymers (**3** and **4**) and the crystal of **6**, where molecules and 1D polymers coexist. The formula of **6** also reveals cocrystallization

Received: September 5, 2011
Published: October 13, 2011

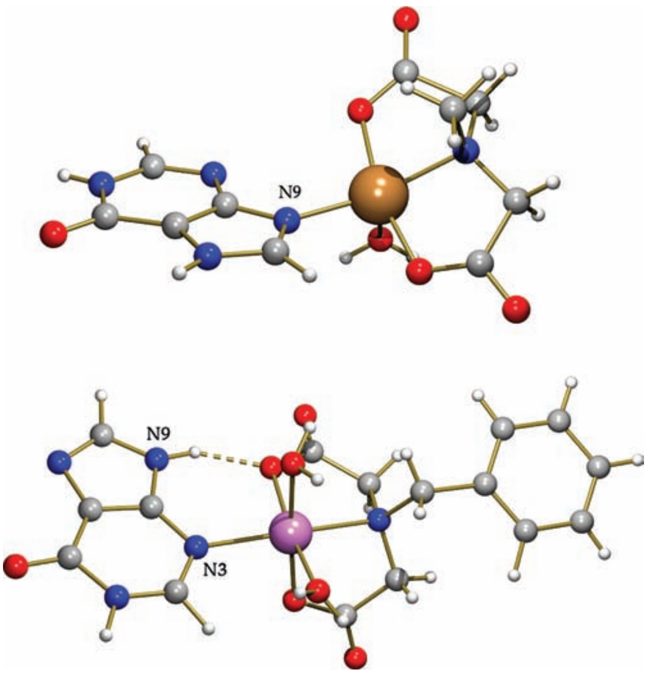
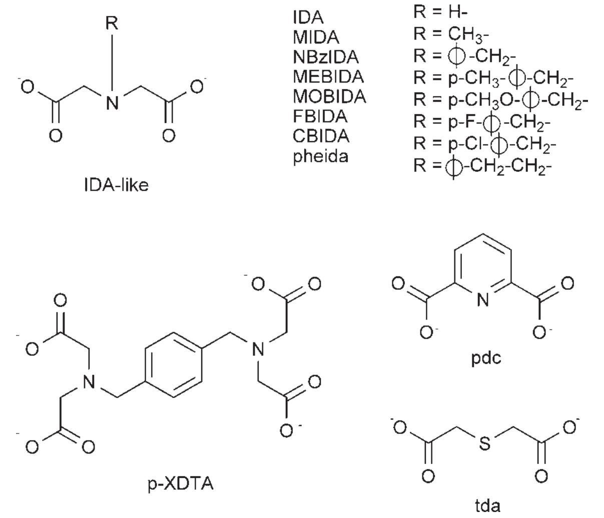


Figure 1. Complex molecules of **2** (top) and **9** (bottom).

of diethyl phthalate (DEph, additive of the partially denatured ethanol). A few related examples of this phenomenon have been previously recorded in CSD.[8] The crystal of **7** has two independent molecules in the asymmetric unit, mainly because of the distinct conformations of the *N*-phenethyl arm in pheida ligands. The binuclear nature of **8** is related to the bridging role of the *p*-XDTA ligand (see Scheme 1). Noteworthy, because copper(II) binds to the most basic N9 donor of Hhyp, this implies the use of the tautomer H(N7)hyp. The structures of compounds **1**−**8** are in accordance with a large number of ternary compounds displaying IDA-like chelators and one N-heterocyclic donor atom supplied by an appropriate coligand. As can be checked in the CSD, related binary copper(II) complexes have the chelating IDA-like ligand in *fac*-NO+O(apical) or *mer*-NO_2 conformation, whereas ternary complexes with two N-heterocyclic donors atoms from other coligands show the IDA-like chelator in an imposed *fac*-NO+O(apical) conformation.

The reported ternary compounds with cobalt(II) (**9**−**13**) or nickel(II) (**14**−**18**) have in common the presence of one *N*-benzyl-like iminodiacetate chelator. All of these compounds are molecular complexes where the metal exhibits a typical octahedral coordination (Figure 1, bottom). In these cases, the iminodiacetate moiety adopts a *fac*-NO_2 conformation with the M−N(IDA-like) distance as the longest coordination bond. This family of compounds shows the metal binding of Hhyp by means of the bond M−N3 reinforced by an intramolecular interligand N9−H···O(coordinated carboxyl) interaction. The M−N3-[H(N9)hyp] bond falls trans to the M−N(IDA-like) bond; thus, these molecules are *cis*-diaqua complexes. Indeed, in addition to the four binary complexes reported herein (**11b**, **14b**, **17b**, and **18b**), all of the binary M−(IDA-like) chelates (M = Co, Ni, or Zn) reported in the CSD have the iminodiacetate moiety in *fac*-NO_2 conformation, irrespective of the presence of any other coligands. Therefore, the available structural information strongly suggests that the octahedral chemistry of cobalt(II) and nickel(II), and probably of zinc(II), induces *fac*-NO_2 conformation to the iminodiacetate moiety. It should stand out that the reported compounds (**1**−**18**) represent two new metal binding patterns for neutral Hhyp: by N9 or by N3 in cooperation with an intramolecular interligand N9−H···O interaction.

Scheme 1. Formulas of the Chelating Ligands Used in the Present Work



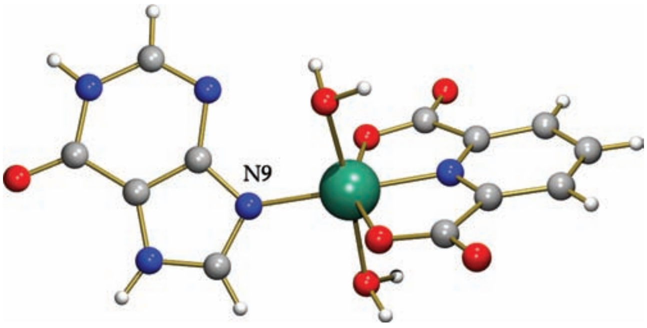


Figure 2. Complex molecule of **21**.

In order to discern whether the two latter molecular recognition modes of hypoxanthine, with iminodiacetate−metal chelates, are driven by the metal coordination polyhedron or the iminodiacetate moiety conformation, compounds **19**−**22** were synthesized using 2,6-pyridinedicarboxylate (pdc) as the chelating agent, which imposes *mer*-NO_2 conformation (Figure 2). Interestingly, compound **19** exhibits a 4 + 1 copper(II) coordination, whereas the cobalt(II), nickel(II), or zinc(II) complexes (**20**−**22**) show a typical octahedral coordination. In these four molecular complexes, hypoxanthine is bonded to the metal via M−N9 using the H(N7) tautomer. Then, we conclude that the IDA moiety conformation is the main driving factor that determines the molecular recognition between the metal chelate and Hhyp.

Likewise, we wonder if the scope of our conclusion could be extended to other chelating ligands; hence, we prepared compound **23**. In this case, the metal exhibits a 4 + 1 coordination, but the tridentate thiodiacetate (tda) ligand adopts a rather unusual *fac*-SO+O(apical) conformation (Figure 3). Moreover, the molecular recognition pattern involves the formation of Cu−N9[H(N7)hyp]. The aqua ligand is trans to the Cu−S bond.

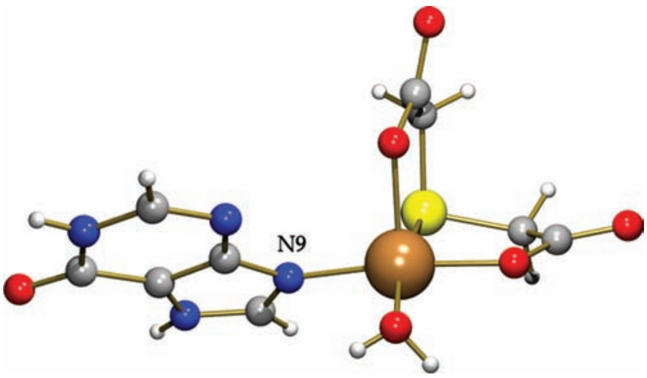


Figure 3. Complex molecule of **23**.

A search in the CSD reveals only eight copper(II) compounds with tda, among which only six display tridentate chelating tda. In these latter compounds, five exhibit tda in *fac*-O_2+S(apical) conformation, whereas only one adopts *fac*-SO+O(apical) conformation. Indeed, tda seems to be unable to act as a tridentate chelating agent with *mer*-SO_2 conformation, a fact that should be related to the size of the central S-donor atom. Consequently, the structure of compound **23** strongly suggests that the main conclusion of this work seems applicable only to ternary complexes with iminodiacetate and very closely related ligands, such as pdc. Furthermore, the molecular recognition between hypoxanthine and IDA-like chelates is radically different from that reported for adenine. Indeed, four different copper(II) binding patterns [Cu−N7, Cu−N3, or $Cu_2(\mu_2\text{-N7,N9})$ and $Cu_2(\mu_2\text{-N3,N7})$] have been described for adenine depending on the *N*-alkyl-, *N*-benzyl-, or *N*-phenethyliminodiacetate ligand, respectively.[9]

Nevertheless, the most remarkable contribution of this work is the correlation between the chelating ligand conformation and the metal binding pattern of hypoxanthine as discussed herein. A recent paper also claimed a unique example where the ligand conformation drives chiral generation and symmetry-breaking crystallization, inducing the separation of two enantiomorphs of a mixed-ligand zinc(II) polymeric complex from an achiral precursor.[10]

■ ASSOCIATED CONTENT

Ⓢ Supporting Information. Formula and structural plots of all of the compounds reported in this work (S1 and S2) as well as tables with relevant spectral properties and thermal stability information (S3). This material is available free of charge via the Internet at http://pubs.acs.org. The atomic coordinates for these structures have been deposited with the Cambridge Crystallographic Data Centre (CCDC 695340−695345 and 834987−835007). The coordinates can be obtained, upon request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, U.K. Additional spectroscopic (FT-IR and UV−vis) and thermal (TGA) analyses for the reported compounds have been carried out by the authors. For further information, please contact the corresponding author.

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■ ACKNOWLEDGMENT

We gratefully acknowledge "Factoría Española de Cristalización" CONSOLIDER INGENIO-2010 and MICINN-Spain (Project MAT2010-15594) for financial support on this research. A.D.-M. also thanks ME-Spain for a predoctoral FPU fellowship.

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