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Chemical and biological studies of gold(III) complexes with uninegative bidentate N–N ligands †

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Three new gold(III) complexes with uninegative bidentate N–N ligands ([Au(pla)Cl_2] (**1**), Hpla = picolinamide; [{Au(pz)Cl_2}$_2$] (**2**), Hpz = pyrazole; [{Au(mpz)Cl_2}$_2$] (**3**), Hmpz = 3-methylpyrazole) have been synthesized and characterized spectroscopically. The crystal structure of **1** contains one five-membered chelated ring and two *cis*-oriented chloride anions. It is the closest Au(III) analogue to cisplatin with an N–H group in the molecule and it forms a hydrogen bond with the carbonyl from adjacent molecule. The crystal structure of **2** shows a symmetrical six-membered Au(N–N)$_2$Au ring. The two N–N bridging bonds and two gold atoms adopt a boat conformation, a configuration which thermodynamically stabilizes the complex. The two gold centres are square planar, each coordinated by two *cis*-oriented chlorides and nitrogens, respectively. These three new complexes have been tested for cytotoxic properties *in vitro* against MOLT-4 (human leukemia) and C2C12 (mouse tumour) cell lines. The results show that these complexes are slightly more cytotoxic than the clinically used cisplatin.

Introduction

There has been recent interest in the chemistry and biochemistry of Au(III) analogues of Pt(II) antitumour drugs.[1–5] Although Au(III) complexes containing N–O$^-$ and N–C$^-$ chelated ligands have been reported recently and some have been tested for biological activity,[1–7] there have not been any reports about the chemical and biological properties of Au(III) complexes with N–N$^-$ chelating ligands. The strong polarizing property of Au(III) leads to the deprotonation of acetyl groups and formation of a Au–CH_2CO species, which was found in our work during gold carboxylate complex synthesis as well as recent literature.[7–13] As the N–H bond is weaker than the C–H bond, it is easy to deprotonate an amide group to form a Au–N$^-$ bonded complex. Sadler *et al.* reported a Au(III) complex [Au(Gly–Gly-L-His–H_{-2})]Cl·H_2O (Gly–Gly-L-His = glycylglycyl-L-histidine) with two deprotonated amide nitrogens.[14] Several other Au(III) complexes with deprotonated amine nitrogens have been reported recently by Rossignoli *et al.*[15] All these show there has been an increase in research interest on Au(III) complexes with deprotonated nitrogen in the field of bioinorganic chemistry.

In this work, three new Au(III) complexes with N–N$^-$ chelating ligands have been synthesized and characterized. Picolinamide is a suitable ligand to prepare a Au(III) complex with deprotonated nitrogen while keeping the complex neutral. [Au(pla)Cl_2] (Hpla = picolinamide) is structurally very close to cisplatin and contains an N–H that structure–function studies show is necessary for anti-cancer activity.

I

II

The pyrazole nucleus, **I**, is thermally and hydrolytically very stable. As a ligand, it usually coordinates to metals and metalloids through the 2-N (the 'pyridine nitrogen'). When deprotonated, pyrazole becomes the pyrazolide ion, **II**, which can coordinate through both nitrogen atoms as an exobidentate ligand of C_{2v} symmetry. The nucleophilicity of the nitrogens and their accessibility may be varied through appropriate ring substitution.[16–19] Despite these attractive features and the vigorous development of pyrazole chemistry in general,[20] the chemistry of pyrazole derivatives with Au(III) has received scant attention until now. Pyrazole itself can be used as an inhibitor of liver alcohol dehydrogenase, and antitumour agent. Pyrazole (Hpz) and 3-methylpyrazole (Hmpz) are employed here as uninegative, 1,2-dihapto exobidentate ligands to bridge two gold atoms. In this work, two dimer compounds [{Au(pz)Cl_2}$_2$] and [{Au(mpz)Cl_2}$_2$] with N–N$^-$ bridging units have been synthesized and characterized spectroscopically.

Experimental

Sodium tetrachloroaurate(III) dihydrate, picolinamide, and 3-methylpyrazole were obtained from Aldrich Chemical Co. Milwaukee, Wisconsin, USA. Pyrazole and other reagents were purchased from Fluka Chemie AG, Buchs, Switzerland.

NMR spectra were recorded on a Bruker ACF 300 (^{1}H, ^{13}C) spectrometer at 25 °C. Spectra were referenced to solvent. Electronic absorption spectra were recorded on a Shimadzu UV-240 spectrophotometer as Nujol mulls. The infrared spectra (KBr pellet) were recorded using an FTS165 Bio-Rad FTIR spectrophotometer in the range 4000–450 cm^{-1}. The elemental analyses were performed in the Microanalytical Laboratory, Department of Chemistry, National University of Singapore.

[Au(pla)Cl_2], 1

In a 50 ml round bottom flask, sodium tetrachloroaurate(III) dihydrate (0.40 g, 1.0 mmol) was dissolved in water (20 ml). Picolinamide (0.16 g, 1.1 mmol) in water (10 ml) was added dropwise to the gold solution and a yellow solid formed immediately. The resulting yellow suspension was stirred in the dark in a water bath at 30 °C for 2 days. It was then filtered, washed with water and dried *in vacuo*. The yellow powder was extracted with acetone (5 × 10 ml) and the extracts concentrated to *ca.* 10 ml. Yellow crystals formed on slow evaporation in a freezer at *ca.* −10 °C for 2 days were filtered off, washed with cold acetone, and dried at ambient temperature. Yield: 0.22 g (56%). Anal. for $C_6H_5AuN_2OCl_2$ (calc. in parentheses) C, 18.3(18.5); H, 1.4(1.3); N, 7.3(7.2); Cl, 18.3(18.3); Au, 48.4(48.6)%. ^{1}H NMR (DMSO-d_6): δ 9.21 (1H, d), 8.90 (1H, s),

† Electronic supplementary information (ESI) available: Least-squares planes and dihedral angles. See http://www.rsc.org/suppdata/dt/b3/b309310g/

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8.52 (1H, t), 8.04 (1H, t), 7.94 (1H, d). ^{13}C NMR (DMSO-d_6): δ 176.1 (C=O), 153.4 (C5), 150.6 (C1), 150.0 (C3), 135.3 (C2), 133.2 (C4).

[{Au(pz)Cl$_2$}$_2$], 2

Pyrazole (0.15 g, 2.1 mmol) in ethanol (10 ml) was added dropwise to an aqueous solution (20 ml) of sodium tetrachloroaurate(III) dihydrate (0.80 g, 2.0 mmol) with stirring over 5–10 min. [Au(Hpz)Cl$_3$] immediately separated as a yellow solid and stirring was continued for 30 min. The yellow suspension was filtered using a sintered glass filter funnel, washed well with water and dried *in vacuo* to yield [Au(Hpz)Cl$_3$] (0.68 g (92%)). Anal. for $C_3H_4AuN_2Cl_3$ (calc. in parentheses) C, 9.9(9.7); H, 1.0(1.1); N, 7.6(7.5); Au, 53.4(53.1)%.

A suspension of [Au(Hpz)Cl$_3$] (0.56 g, 1.5 mmol) was heated under reflux in toluene (40 ml) for 8 h and then concentrated to dryness. The residue was extracted with dichloromethane (3 × 20 ml) and the extracts were concentrated to *ca.* 10 ml. Yellow crystals of **2** were obtained by slow evaporation in a freezer at *ca.* −10 °C. Yield: 0.39 g (78%). Anal. for $C_6H_6AuN_4Cl_4$ (calc. in parentheses) C, 10.7(10.7); H, 0.9(0.9); N, 8.3(8.4); Cl, 21.0(21.2); Au, 58.6(58.8)%. ^{1}H NMR ($CDCl_3$): δ 7.99 (4H, d), 6.72 (2H, t). ^{13}C NMR ($CDCl_3$): δ 150.4 (C1, C3, C4, C6), 142.1 (C2, C5).

[{Au(mpz)Cl$_2$}$_2$], 3

A solution of 3-methylpyrazole (0.17 ml, 2.1 mmol) in acetone (10 ml) was added dropwise to a stirred solution of sodium tetrachloroaurate(III) (0.80 g, 2.0 mmol) in water (20 ml). A yellow solid formed immediately and the suspension was stirred in a water bath (50 °C) for 3 h. Heating was removed and stirring continued for 1 h. The solid was filtered, washed well with water and dried *in vacuo*. It was then extracted with dichloromethane (3 × 20 ml) and the solution was concentrated to *ca.* 10 ml. **3** reprecipitated on addition of diethyl ether to the concentrated CH_2Cl_2 solution. Yield: 0.57 g (82%). Anal. for $C_8H_{10}Au_2N_4Cl_4$ (calc. in parentheses) C, 13.9(13.7); H, 1.3(1.4); N, 8.1(8.0); Cl 20.5(20.3); Au, 56.2(56.5)%. ^{1}H NMR ($CDCl_3$): δ 7.79 (d), 6.48 (d); 7.75(d), 6.49(d), 2.55(s). ^{13}C NMR ($CDCl_3$): δ 151.2, 141.4, 109.1; 150.9, 140.8, 109.4, 14.4.

X-ray crystallography

The diffraction experiments were carried out on a Bruker AXS SMART CCD diffractometer. The program SMART[21] was used for collecting the intensity data, for reflections indexing and for the determination of lattice parameters, SAINT[21] was used for integration of the intensity of reflections and scaling, SADABS[22] was used for absorption correction and SHELXTL[23] for space group and structure determination, least-squares refinements on F^2. All non-H atoms were refined with anisotropic thermal parameters. All H atoms were assigned isotropic displacement parameters. Selected crystallographic data and refinement details are displayed in Table 1.

CCDC reference numbers 216797, 216798.

See http://www.rsc.org/suppdata/dt/b3/b309310g/ for crystallographic data in CIF or other electronic format.

Cytotoxicity testing

Comparative cytotoxicity against the MOLT-4 human leukemia and C2C12 mouse tumour cell lines was assessed. A typical assay was set up by dispensing 30000 MOLT-4 cells in 70 µl RPMI 1640 medium supplemented with 10% foetal calf serum in to each well of a 96-well plate. The C2C12 cells were cultured in Dulbecco's modified Eagle's medium with 4 mM L-glutamine adjusted to contain 1.5 g L^{-1} sodium bicarbonate, 4.5 g L^{-1} glucose and 1.0 mM sodium pyruvate, 90%; fetal bovine serum, 10%. The test fractions were dissolved in DMSO and added in 10 µl aliquots such that the final concentration of DMSO was 1.25% (v/v) in all wells. Controls received DMSO only. Following incubation of cells with test fractions for 14–16 h at 37 °C and 5% CO_2, 20 µl of a 5 mg $^{-1}$ solution of 3[4,5-dimethylthiazol-2-yl]2,5-diphenyltetrazoliumbromide (MTT) was added into each well (MTT final concentration 1 mg^{-1}). Three hours later, 100 µl of lysing solution (20% sodium dodecyl sulfate dissolved in 50% DMF, pH adjusted to 4.7 with acetic acid) was added to each well. Cell lysis was facilitated by mechanical disruption and mixing, after which absorbance was read at 570 nm against the standard mixture of RPMI 1640 medium, MTT, and lysing solution as blank.

Table 1 Crystallographic data and structure refinement details for **1** and **2**

Complex	**1**	**2**
Formula	$C_6H_5AuCl_2N_2O$	$C_6H_6Au_2N_4Cl_4$
Formula weight	388.99	669.88
Temp/K	293(2)	293(2)
Crystal system	Monoclinic	Monoclinic
Space group	*P*2(1)/*c*	*P*2(1)/*n*
a/Å	8.7791(2)	9.7067(1)
b/Å	5.9621(1)	11.3016(2)
c/Å	17.2028(4)	11.9686(2)
β/°	90.937(1)	90.185(1)
V/Å^3	900.31(3)	1312.96(3)
Z	4	4
μ/mm^{-1}	16.883	23.112
Collected reflns	4880	7989
Independent reflns	1840	3190
R_{int}	0.0260	0.0350
Final R_1[a] [$I > 2\sigma$]	0.0273	0.0323
Final wR_2[b] [$I > 2\sigma$]	0.0717	0.0754

[a] $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$. [b] $wR_2 = [\Sigma w(F_o^2 - F_c^2)^2/\Sigma w(F_o^2)^2]^{1/2}$

Results and discussion

Crystal structures

The crystal structures of **1** and **2** were confirmed by X-ray crystallography. The synthesis and crystal structure of **1** has been published recently.[24] An ORTEP diagram for **1** with numbering scheme is shown in Fig. 1. Selected bond distances and angles are given in Table 2. In **1**, gold has essentially a square-planar N_2Cl_2 coordination sphere, with the gold centre and the four ligand atoms being closely coplanar (mean deviation from the least-squares plane is 0.074 Å). Complex **1** carries one five-membered chelate ring and two *cis*-oriented chloride anions. The picolinamide ligand is deprotonated at N(2), and the Au–N(2) bond length (1.972(4) Å) is significantly shorter than the Au–N(1) bond (2.044(5) Å). The Au–N(2) bond distance is very similar to those reported in other Au(III) complexes with negatively charged nitrogen,

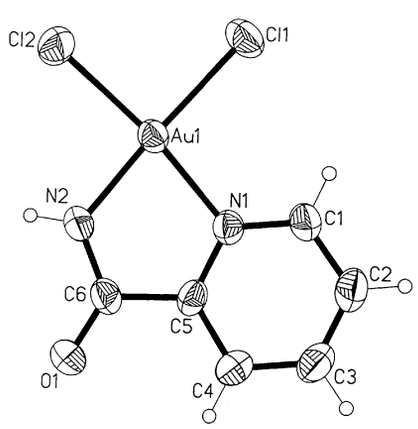


Fig. 1 An ORTEP view of **1** showing the numbering scheme.

Table 2 Selected bond lengths (Å) and angles (°) for **1**

Au(1)–N(1)	2.047(5)	Au(1)–N(2)	1.969(5)
Au(1)–Cl(1)	2.2971(14)	Au(1)–Cl(2)	2.2613(15)
C(5)–N(1)	1.356(8)	C(5)–C(6)	1.503(8)
C(6)–N(2)	1.331(8)		
N(1)–Au(1)–N(2)	81.18(19)	Cl(1)–Au(1)–Cl(2)	91.63(6)
N(1)–Au(1)–Cl(1)	95.80(14)	N(2)–Au(1)–Cl(2)	91.39(15)
N(1)–Au(1)–Cl(2)	172.53(14)	N(2)–Au(1)–Cl(1)	176.97(15)
C(6)–N(2)–Au(1)	118.2(4)	C(5)–N(1)–Au(1)	111.8(4)
C(5)–C(6)–N(2)	112.0(5)	C(6)–C(5)–N(1)	116.8(5)

[Au(Gly–Gly-L-His–H_{-2}]Cl·H_2O (2.006(10), 1.941(9) Å),[14] and $[Au(L^4–H)]^{2+}$ (L = 1,9-diamino-5-methyl-5-nitro-3,7-diazanonan-3-ido) (2.004(7) Å and 2.016(8) Å).[15] Notably, the Au–Cl(1) bond length (2.297(1) Å) is longer than the Au–Cl(2) bond (2.261(1) Å), which reflects the *trans* influence of an amido-group. This result is consistent with the *trans* influence of an amido-group being greater than that of an amine, a characteristic observed earlier in $[Au(dien)Cl]^{2+}$ and $[Au(dien\text{-}H)Cl]^{+}$,[25] where the Au–Cl bond elongates from 2.237(8) Å in the former to 2.33(1) Å in the latter.

This appears to be the closest gold(III) structural analogue to cisplatin, as the complex contains an N–H group and is neutral. The N–H functionality is important in biological activity because it is believed that in Pt(II) complexes the N–H group is required as a hydrogen bond donor functionality with biomolecules. Interestingly, there is still one hydrogen atom on the deprotonated amino-group giving a hydrogen bond between this and the oxygen of the carbonyl group on another molecule leading to hydrogen-bonding dimer in the packing diagram as shown in Fig. 2.

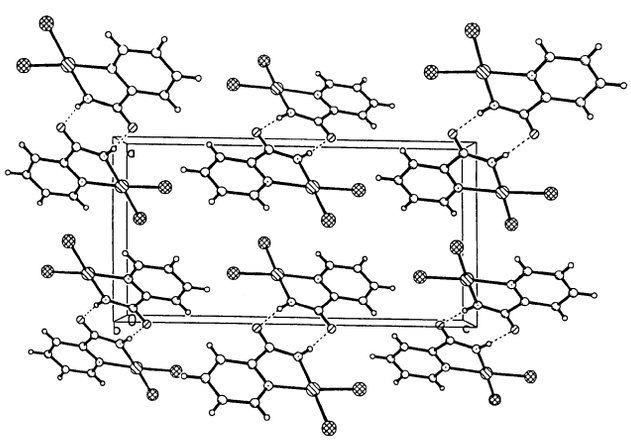


Fig. 2 Packing diagram of **1** showing hydrogen-bonding.

The crystal structure of **2** exhibits a square planar coordination geometry for the gold centre which has features common with **1**. Perspective view for **2** with numbering scheme shows the symmetrical six-membered $Au(N–N)_2Au$ ring in the boat conformation (Fig. 3). Selected bond distances and angles are given in Table 3. Two planes through one pyrazoyl ring C(1)–C(3), N(1) and N(2) and the group of atoms Au(1), N(1), N(2), and Au(2) show that the sets of atoms are almost co-planar, with a dihedral angle of 3.7°. This small deviation from coplanarity would certainly not hinder the delocalization of 6p electrons in each C_3N_2 moiety, which presumably gives an added stability to the boat conformation. Important least-squares planes and dihedral angles for **2** are listed in Table S1 (ESI). †

The two gold centres are square-planar, coordinated by *cis*-oriented chlorides and nitrogens. The two AuN_2Cl_2 fragments in the dimer are approximately planar. The N(1)–Au(1)–N(4) and N(2)–Au(2)–N(3) angles of 89.3(3) and 88.8(3)° are nearly the ideal 90°. The two N–N bridging bonds and two gold atoms

Table 3 Selected bond lengths (Å) and angles (°) for **2**

Au(1)–N(1)	2.022(6)	Au(1)–N(4)	2.016(6)
Au(1)–Cl(1)	2.281(2)	Au(1)–Cl(2)	2.268(2)
Au(2)–N(2)	2.026(6)	Au(2)–N(3)	2.021(7)
Au(2)–Cl(3)	2.280(2)	Au(2)–Cl(4)	2.284(2)
N(1)–N(2)	1.348(8)	N(3)–N(4)	1.350(8)
Cl(1)–Au(1)–Cl(2)	89.43(8)	N(1)–Au(1)–N(4)	89.3(3)
Cl(1)–Au(1)–N(1)	90.9(2)	Cl(2)–Au(1)–N(4)	90.3(2)
Cl(1)–Au(1)–N(4)	178.9(2)	Cl(2)–Au(1)–N(1)	179.3(2)
Cl(3)–Au(2)–Cl(4)	92.2(8)	N(2)–Au(2)–N(3)	88.8(3)
Cl(3)–Au(2)–N(2)	87.9(2)	Cl(4)–Au(2)–N(3)	91.1(1)
Cl(3)–Au(2)–N(3)	176.4(2)	Cl(4)–Au(2)–N(2)	177.6(2)
N(2)–N(1)–Au(1)	122.6(4)	N(1)–N(2)–Au(2)	122.9(5)
N(3)–N(4)–Au(1)	123.0(5)	N(4)–N(3)–Au(2)	122.4(5)

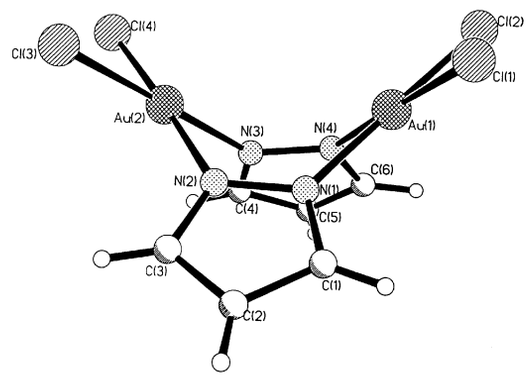


Fig. 3 A perspective view of **2**.

adopt a boat conformation, a configuration that thermodynamically stabilizes the complex. The molecule as a whole has C_{2v} symmetry, whilst the two gold atoms are essentially located in this plane. The four Au–N bond lengths are very close to one another and the mean Au–N distance (2.021(5) Å) is not significantly different from those in $[Au(ppy)Cl_2]$ (2.034(13) Å) and $[Au(ppy)(ace)_2]\cdot H_2O$ (2.028(6) Å).[7] However, this mean Au–N distance is considerably shorter than Au–N (amino-nitrogen) distances quoted in $[Au(dmtc)(damp)]BPh_4$ (2.23(2) Å) (dmtc = $(CH_3)_2NCS_2$, damp = o-$C_6H_4CH_2N(CH_3)_2$)[26] and $[Au(damp)(H_2NC_6H_4S)]ClO_4$ (2.138(4) and 2.118(4) Å),[27] and is longer than Au–N (amido-nitrogen) bond lengths in **1** (1.972(4) Å), [Au(Gly–Gly-L-His–H_{-2}]Cl·H_2O (2.006(10), 1,941(9) Å),[14] and $[Au(L^4–H)]^{2+}$ (L^4 = 1,9-diamino-5-methyl-5-nitro-3,7-diazanonan-3-ido) (2.004(7) and 2.016(8) Å).[15] This difference presumably arises from the effect of delocalization of 6p electrons in the pyrazoyl ring. The bond distances and angles with the pyrazoyl ring approximate to values of other pyrazoyl dimers.[28–33] The bond distances compare well with the corresponding ones in $[GaD_2\cdot C_3H_3N_2]_2$ (N–N 1.342(10), C–N 1.339(11)–1.353(12), and C–C 1.340(15)–1.365(15) Å).[34]

Spectroscopic studies

The UV-vis spectrum of **1** in dichloromethane has a sharp band at 318 nm and a moderate band at 268 nm. The former could be assigned to a $p \longrightarrow d_{x^2-y^2}$ chloride to gold charge transfer transition; the later may be assigned as py ⟶ Au charge transfer LMCT. Both complexes **2** and **3** have similar electronic spectra in the dichloromethane, with a strong chloride to gold charge transfer at 316 nm. There are also two moderately intense bands at 228 and 286 nm, which are tentatively assigned as pyrazole centred $\pi \longrightarrow \pi^*$ transitions.

The IR spectrum of **1** shows a moderate, broad band at 3327 cm^{-1}, which is attributed to the N–H stretching frequency. Other functional groups in the complex absorb normally. A characteristic feature in the IR spectra of the two pyrazole complexes in **2** is the disappearance of the N–H stretching

Table 4 IC_{50} values (μM) against MOLT–4 and C2C12 cell lines

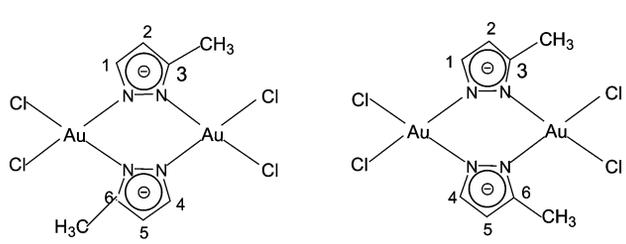
Complex	**1**	**2**	**3**	Cisplatin
MOLT-4	3.1	1.5	1.8	6.8
C2C12	8.0	6.0	5.0	14.7

frequency, which is shown in the $[Au(Hpz)Cl_3]$ at 3442 cm^{-1}. This feature is also useful to monitor the extent of the deprotonation reaction of the 1-H. The C–C, C–N, and N–N stretching modes of the pyrazole ring consist of peaks at 1697, 1648, 1606, and 1481 cm^{-1}.[35] In the IR spectrum of **3**, a strong peak at 3095 cm^{-1} is assigned to the C–H stretching frequency of the methyl group.

The ^1H NMR data of **1** in different solvents are shown in Table S2 (ESI). † For the picolinamide ligand, substantial solvent shifts are observed. There are four distinct peaks for protons on the pyridine ring and a significant positive coordination shift is seen for the adjacent proton of nitrogen. The amide nitrogen presents a broad peak in organic solvents, which was not observed when a drop of D_2O was added. The signal for the amide hydrogen shows substantial positive coordination shifts in cases where the amide is known to chelate. This is a useful diagnostic of chelation. The ^{13}C spectrum in DMSO-d_6 shows five peaks at δ 153.4, 150.6, 150.0, 135.3, and 133.2 for the pyridine ring and a peak at δ 176.1 for the carbonyl group.

The ^1H and ^{13}C NMR data of **2** and **3** in $CDCl_3$ are shown in Table S3 (ESI). † The ^1H NMR data of **2** was useful for structure assignment. It invariably indicated equivalence of the 1,3,4,6 and 2,5 positions (Fig. 3), respectively. The 1,3,4,6-hydrogens in CD_3Cl are a doublet at δ 7.99 and the 2,5-hydrogens a triplet at δ 6.72. Both show positive coordination shifts compared with free pyrazole. The ^{13}C spectrum of **2** in CD_3Cl showed only two peaks at δ 142.1 (C^2 or C^5) and 150.4 (C^1, C^3, C^4 or C^6) due to its symmetric structure.

In the ^1H NMR spectrum of **3** in CD_3Cl, there are two pairs of doublets at δ 7.79 and 6.48, 7.75 and 6.49, which are slightly upfield compared with **2**. This is possibly due to the electron-releasing effect of methyl. The ^{13}C spectrum shows two sets of signals with one set of three pyrazoyl peaks at δ 109.1, 141.4 and 151.2, and another set at δ 10.4, 140.8 150.9. A single methyl carbon peak is observed at δ 14.4. The appearance of two sets of ^1H and ^{13}C signals for pyrazoyl could be attributed to the possibility of two isomers for **3** (Scheme 1). The exact structure of **3** would benefit from an X-ray crystallography structure determination.



Transoid, **Isomer 1** *Cisoid,* **Isomer 2**

Scheme 1

Cytotoxicity studies

In vitro cytotoxic activity of complexes including cisplatin as a comparison were determined against the human tumour cell line MOLT-4 and the mouse tumour cell line C2C12. Cytotoxicity data are given as IC_{50} values, the concentration of complex required to inhibit the growth of cells by 50% compared with that of a control, in Table 4. The results show that the cytotoxicity profile is similar for all the three Au(III) complexes, with IC_{50} values for both cell lines in the low-micromolar range. As observed in our previous work,[7] it is postulated that gold may play a vital role in biological activity, despite these complexes having different ligands. Compared with the result for cisplatin, these gold complexes showed greater toxicity (lower IC_{50} values) on the MOLT-4 and C2C12 cell lines. Such differential cytotoxicity has been used as an indicator of antitumour activity.[2,6,36] We suggest that these new Au(III) complexes deserve further biological studies against a wide range of tumour cell lines and *in vivo* xenograft studies.

Conclusion

Three new Au(III) complexes with chelated monoanionic $N–N^-$ ligands have been synthesized and characterized. These Au(III) complexes structurally resemble cisplatin and have higher solubility than for their cholo precursor as they could be dissolved with warming and ultrasonication. These complexes have good stability in aqueous solution and in air as solids. **1** has an interesting N–H bond in its molecule, resulting in a close structural resemblance to cisplatin. The N–H bond leads to the formation of hydrogen bonds between pairs of molecules and may play an important role in its biological activity. The crystal structure of **2** shows a dimer with two $N–N^-$ bridging moieties. The symmetrical six-membered $Au(N–N)_2Au$ ring adopts a boat conformation.

The *in vitro* cytotoxic assays of these Au(III) complexes on MOLT-4 and C2C12 cell lines show that they have comparable cytotoxicity to cisplatin. This finding leads us to believe that these Au(III) complexes have potential antitumour properties for some human tumours and full evaluation and exploitation is now needed to investigate the possibility of clinical use for these Au(III) complexes.

Acknowledgements

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