ISSN: 0975 -8542

Journal of Global Pharma Technology

Available Online at: www.jgpt.co.in

RESEARCH ARTICLE

Synthesis, Structure and Antibacterial Activity of 1, 4-bis (1-benzimidazolyl) butane Complexes with some Transition Metal Salts

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Abstract

This study presents the synthesis, characterization and antibacterial activity of Mn^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+} and Ag^{+} complexes derived from the ligand 1,4-bis(1-benzimidazolyl) butane (Dbz). The ligand and its complexes were characterized by using different techniques including IR, Uv-Vis, ^{1}H and ^{13}C NMR and elemental analysis CHN. According to the abovementioned techniques, a polymeric structure was proposed to the prepared complexes. Further, the structure of Ag(I) complex was confirmed by single crystal X-ray diffraction technique which reveals the polymeric structure trigonal geometry around the Ag^{+} center. The in vitro antibacterial activity of the prepared ligand and complexes were tested against the standard Escherichia coli (E. coli ATCC 25922), environmental Bacillus sp. and 16 clinical bacterial isolates (both Gram-positive and Gram-negative bacteria) by using amikacin as a standard antibiotic. All the tested compounds except the Zn(II) complex showed antibacterial activities at minimum inhibition concentration (MIC) level, particularly, the silver complex which shows a significant activity with MIC = 15- 250 µg/ml.

Keywords: *Benzimidazole; Synthesis; Crystal structure; Metal complexes; Antibacterial; Silver.*

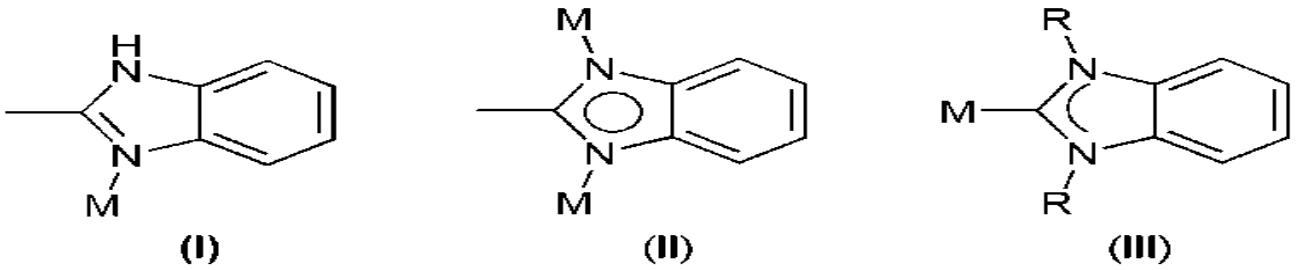
Introduction

Increasing of antibiotic resistance has been a major challenge for public health. Due to this resistance, a dramatic increase in multidrug-resistant human-pathogenic bacteria worldwide has been seen [1-4]. Hence many microbial infections will soon become untreatable [5]. In order to combat drug resistance, several promising strategies have been developed to restore treatment options against infections by resistant bacterial pathogens [6].

The new agents should comprise chemical features that clearly differ from those of in current use agents [7,8]. Most of the heterocyclic compounds are of great interest in pharmaceutical chemistry. Among them, benzimidazole which is a heterocyclic aromatic compound consists of a benzene ring fused with imidazole.

This compound and its derivatives have a wide variety of biological activities such as; anticancer [9-13], antitumor [14,15], antibacterial [4,16,17], antiparasitic [18], antifungal [4,19], and antiulcer [20,21]. Benzimidazole scaffold is structurally analogous to purine and its derivatives might compete with purines, and inhibit DNA replication, exerting powerful antimicrobial action, indicating that they are promising candidates for developing new antimicrobial agents [7,18].

Imidazole and benzimidazole and their derivatives are considered interest as ligands toward transition metal ions. They exhibit different coordination modes (Scheme 1) [22] with a variety of applications, particularly the catalytical [23-25], and biological [26-32], ones.



Scheme 1: Coordination modes of benzimidazoles.

Different studies have reported that the biological activity of benzimidazoles metal complexes is greater than for free ligands [20]. Therefore, their transition metal complexes have been extensively studied. Many researchers reported the transition metal complexes consist of 2-substituted and benzimidazole-mix ligands [33]. Recently, Kücükbay et al. [33] reported the preparation and characterization of ten 3-phenylpropyl, (4-morpholinyl)ethyl, and (1-piperidinyl)ethyl substituted benzimidazole or 5-nitrobenzimidazole cobalt(II), iron(II), and zinc(II) complexes.

More recently, Apohan et al. [10a] reported a series of Co(II) and Zn(II) complexes of 1-(4-substitutedbenzyl)-1*H*-benzimidazoles. The prepared complexes were investigated against lung cancer cells (A549) and BEAS-2B, and different microorganisms. Some of the investigated complexes showed promising cytotoxic and antimicrobial activities. Therefore, this work aims to synthesis and characterize of Mn(II), Co(II), Ni(II), Cu(II), Zn(II) and Ag(I) complexes of the ligand 1,4-bis(1-benzimidazolyl) butane.

The antibacterial activity of the ligand and its complexes were tested against *Escherichia coli* (*E. coli* ATCC 25922), environmental *Bacillus* sp. and 16 clinical bacterial isolates (both Gram-positive and Gram-negative bacteria), especially urinary tract, diarrhea and wound infections. The results showed that the silver complex was more effective than other complexes against all the tested microorganisms.

Experimental

Materials and Physical Measurements

All the chemicals and solvent used were of reagent grade and used as it is without further purification. FT-IR spectra of the compounds were recorded on KBr disks using a SHIMADZU spectrometer in the range 4000-400 cm^{-1}.

Elemental analysis CHN was carried by Euro EA elemental analyzer CHNS, EA3000 analyzer. Both techniques are available at the department of chemistry- College of science, Al-Mustansiriyah University, Iraq. Uv-visible spectra were recorded using Sp-3000 nano OPTIMA spectrophotometer in rang 200-800 nm, which is available in the department of chemistry- college of science-University of Wasit, Iraq. ^{1}H & ^{13}C NMR spectra were recorded in *d6*-DMSO using Bruker UltraShield™ 500 MHz spectrometer.

X-ray diffraction data were collected using an Agilent SuperNova single crystal X-Ray diffractometer. Mass spectra were recorded using DIONEX, MultiMate 3000 spectrometer. The last three techniques are available at School of Chemistry, University of Leeds, UK.

Synthesis of the ligand 1,4-bis(1-benzimidazolyl)butane

In 250 ml round bottom flask containing 40 ml of DMSO, 2 g (1 mmol) of NaOH and 4.4 g (1 mmol) of benzimidazole were added. The mixture was heated using oil bath at 80-90 ^{o}C for 2 hr with constant stirring. The reaction mixture was slowly cooled to 40-50 ^{o}C, and 1,4-dibromobutane 4.5 g (0.5 mmol) was added and kept at the same condition for 90 min. Then, the mixture was poured into a 500 ml beaker containing 250 ml of water immersed in ice-bath. The resulted off-white precipitate was left to stand and then collected by filtration, washed with distilled water and dried at room temperature.

The yield percentage was 93.33 %. Anal. Cal. For $C_{18}H_{18}N_4$: C, 74.46; H, 6.25; N, 19.30 %, found: C, 74.90; H, 7.13; N, 18.97 %. IR: v (C=N): 1497 cm^{-1}. MS: 291.16 [M+]. ^{1}H NMR (DMSO-*d6* , 500MHz): δ 1.77 (m, 4H, CH_2), δ 4.25 (t, 4H, CH_2-N), 7.17-7.24 (m, 4H, Ar-H), 7.56 (d, *J* =10 Hz, 2H, Ar-H), 7.64 (d, *J* =10 Hz, 2H, Ar-H), 8.20 (s, 2H, NCHN). ^{13}C NMR (DMSO-*d6* , 125 MHz): δ 26.73 (CH_2), δ 43.49

(CH_2-N), 110.33, 119.42, 121.42, 122.22, 133.71, 143.39 (Ar-C), 143.92 (NCHN) ppm.

Synthesis of the Complexes

To a solution of the ligand (1 mmol) dissolved in 10 ml of ethanol, (1 mmol) of the metal salt dissolved in 10 ml of ethanol, was added. The mixture was heated at 50-60 ^{o}C for 1 h with constant stirring. The resulted precipitates were filtered and washed with ethanol and distilled water.

Synthesis of Mn(II) Complex

The complex was prepared as described above from the ligand (1 mmol) and $MnCl_2.6H_2O$ (1 mmol). The reaction produced the complex as a white precipitate (0.77 g, 64 %). Anal. Cal. For $(C_{18}H_{18}Cl_2MnN_4)_n$: C, 51.94; H, 4.36; N, 13.46 %, found: C, 52.29; H, 4.69; N, 13.82 %. IR: v (C=N): 1462 cm^{-1}.

Synthesis of Co(II) Complex

The complex was prepared as described above from the ligand (1 mmol) and $CoCl_2$ (1 mmol). The reaction produced the complex as a blue precipitate (0.73 g, 74.5 %). Anal. Cal for $(C_{18}H_{18}Cl_2CoN_4)_n$: C, 51.45; H, 4.32; N, 13.33%, found: C, 51.72; H, 4.87; N, 13.37 %. IR: v (C=N): 1464 cm^{-1}.

Synthesis of Ni(II) Complex

The complex was prepared as described above from the ligand (1 mmol) and $NiCl_2.6H_2O$ (1 mmol). The reaction produced the complex as a bluish verdant precipitate (0.66 g, 55 %). Anal. Cal for $(C_{18}H_{18}Cl_2N_4Ni)_n$: C, 51.48; H, 4.32; N, 13.34 %, found: C, 51.96; H, 5.09; N, 13.62 %. IR: v (C=N): 1460 cm^{-1}.

Synthesis of Cu(II) Complex

The complex was prepared as described above from the ligand (1 mmol) and $CuCl_2$ (1 mmol). The reaction produced the complex as a yellow-greenish precipitate (0.66 g, 62.8 %). Anal. Cal for $(C_{18}H_{18}Cl_2CuN_4)_n$: C, 50.89; H, 4.27; N, 13.19 %, found: C, 50.60; H, 4.87; N, 12.88%. IR: v (C=N): 1464 cm^{-1}.

Synthesis of Zn(II) Complex

The complex was prepared as described above from the ligand (1 mmol) and $ZnCl_2$ (1 mmol). The reaction produced the complex as a white precipitate (0.67 g, 65 %). Anal. Cal for $(C_{18}H_{18}Cl_2N_4Zn)_n$: C, 50.67; H, 4.25; N, 13.13 %, found: C, 51.03; H, 4.52; N, 13.41 %. IR: v (C=N): 1462 cm^{-1}. ^{1}H NMR (DMSO-d_6 , 500MHz): δ 1.73 (m, 4H, CH_2), δ 4.26 (t, 4H, CH_2-N), 7.24-7.30 (m, 4H, Ar-H), 7.62 (d, J =20 Hz, 2H, Ar-H), 7.80 (d, J =20 Hz, 2H, Ar-H), 8.42 (s, 2H, NCHN). ^{13}C NMR (DMSO-d_6 , 125 MHz): δ 28.89 (CH_2), δ 44.41 (CH_2-N), 111.06, 118.71, 122.52, 123.15, 133.15, 141.08 (Ar-C), 144.45 (NCHN) ppm.

Synthesis of Ag(I) Complex

The complex was prepared as described above from the ligand (1 mmol) and $AgNO_3$ (1 mmol). The reaction produced the complex as a light grey precipitate (0.87 g, 79.8 %). Anal. Cal for $(C_{27}H_{27}AgN_7O_3)_n$: C, 53.56; H, 4.50; N, 16.19 %, found: C, 53.38; H, 4.40; N, 15.96 %. IR: v (C=N): 1460 cm^{-1}. ^{1}H NMR (DMSO-d_6 , 500MHz): δ 1.75 (m, 4H, CH_2), δ 4.24 (t, 4H, CH_2-N), 7.25-7.33 (m, 4H, Ar-H), 7.53 (d, J =10 Hz, 2H, Ar-H), 7.61 (d, J =10 Hz, 2H, Ar-H), 8.43 (s, 2H, NCHN). ^{13}C NMR (DMSO-d_6 , 125 MHz): δ 28.62 (CH_2), δ 44.36 (CH_2-N), 110.89, 118.65, 122.48, 123.21, 133.12, 141.13 (Ar-C), 144.48 (NCHN) ppm.

Antibacterial Activity

Bacterial Isolates

The clinical isolates used in this study were obtained from the Bacteriology Laboratory at Al-Zahraa Hospital in Al-Kut/ Wasit Province/Iraq. In addition, one standard strain (*E. coli* ATCC 25922) was obtained from Central Health Laboratory/ Ministry of Health/ Baghdad/ Iraq. The environmental isolate was obtained in our laboratory by leaving a blood agar plate opened in the laboratory environment for 24 hrs, then the plate was incubated for another 24 hrs at 37°C. The isolate was identified depending on colonial morphology and microscopic appearance in a Gram-stained smear [34].

Determination of Minimum Inhibitory Concentration of Derivatives

Minimum inhibitory concentrations (MICs) of the ligand and its complexes were evaluated against bacteria using the broth microdilution method in 96-well plates [35]. All bacterial isolates were cultured on brain heart infusion agar for 24 hrs at 37°C. The inoculum was prepared by suspending several colonies from this overnight culture in brain heart infusion broth and then adjusted to a 0.5 McFarland standard (approximately 1.5×10^8 CFU/ml). Two-fold serial dilutions of the tested compounds were prepared. The studied compounds were firstly dissolved in DMSO at a concentration of 4 mg/ml (stock solution), then 199 µl of

brain heart infusion broth was added to each well of the microtiter plate. Thereafter, for each compound 200 µl was mixed with brain heart infusion broth in the first well and then the twofold dilution was followed. After that, 1 µl of bacterial suspension (1.5×10^8 CFU/ml) was added to each well to achieve a concentration of 5×10^5 CFU/ml. Each plate was wrapped loosely with parafilm to avoid dehydration.

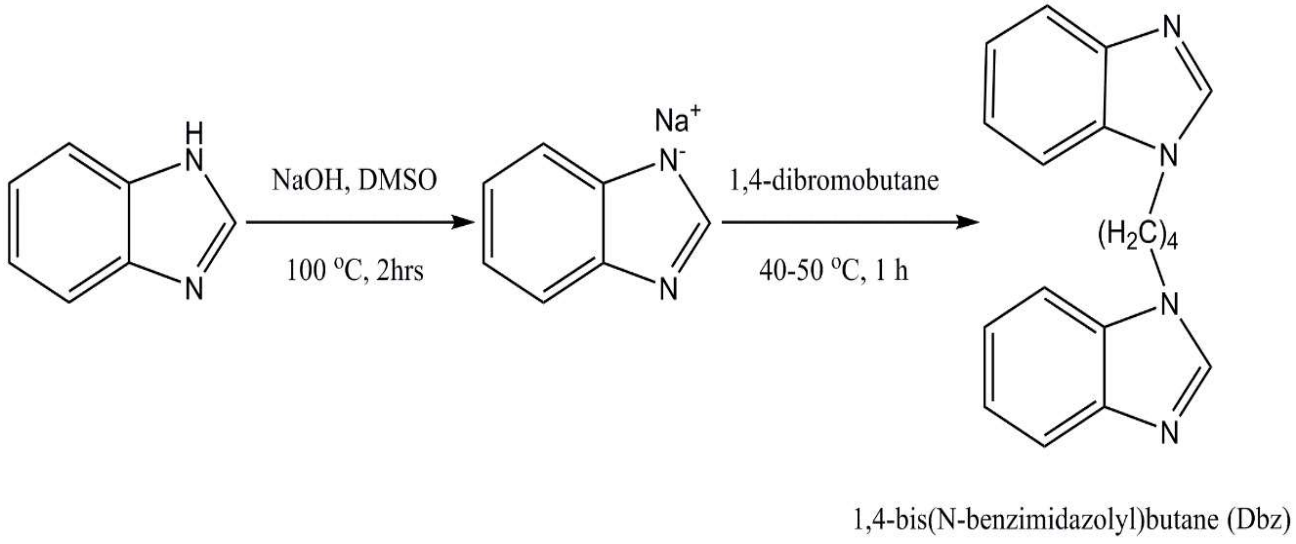
Each plate contains three controls: a row with a broad-spectrum antibiotic (amikasin: 30 µg, Bioanalyse/ Turket) as a positive control, a row with all solutions with the exception of the bacterial solution, and a row with all additions except the tested compounds. The plates were incubated at 37°C for 18-24 h. The presence (turbidity) or absence (clarity) of growth was then assessed visually. The absence of growth was recorded as positive. The lowest concentration at which growth was absent, was taken as the MIC value.

Results and Discussion

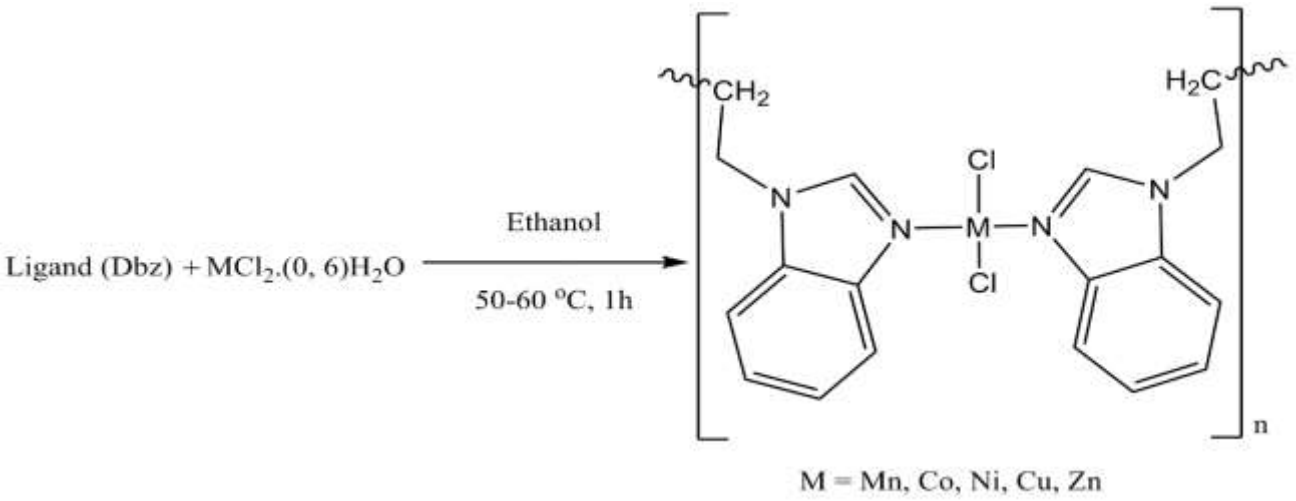
Synthesis and Characterization

The ligand 1,4-bis(1-benzimidazolyl)-butane was prepared according to a procedure published in our previous work with slight modification [36]. An equimolar of benzimidazole and NaOH were reacted in hot DMSO to produce the sodium benzimidazolide salt.

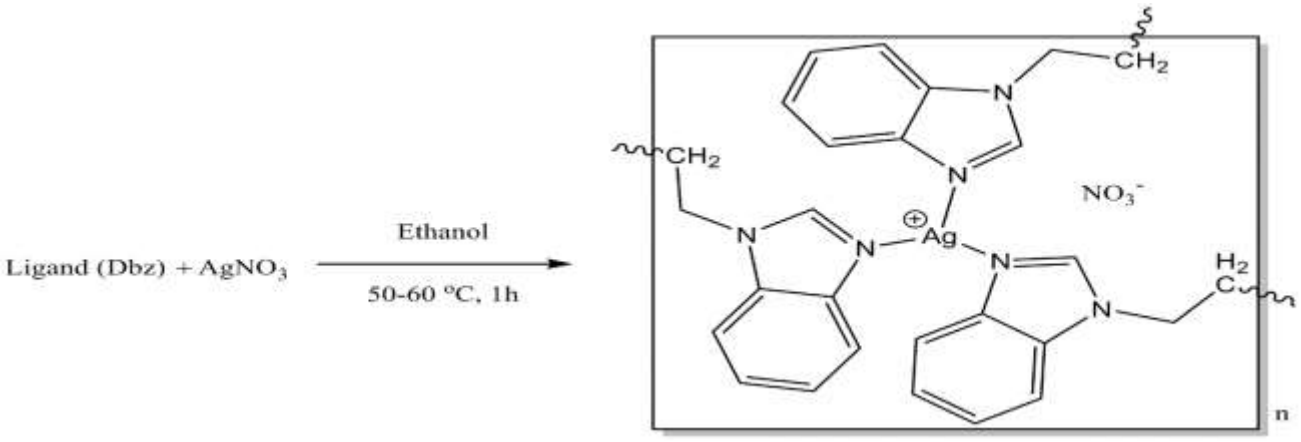
After cooling the mixture to 40 °C, a half equivalent of 1,4-dibromobutane was added and stirred at constant temperature for 2 hrs (Scheme 2). Then the mixture was poured in cooled water to give the product as an off-white precipitate which was collected by filtration. The product was air and moisture stable at room temperature. The reaction of equimolar ethanolic solutions of the ligand and appropriate metal salt afforded the complexes as solid products after heating the mixture between 50-60 °C for 1 h (Scheme 3a and 3b).



Scheme 2: Synthesis of the ligand 1,4-bis(N-benzimidazolyl)butane (Dbz)



Scheme 3a: Synthesis of Mn(II), Co(II), Ni(II), Cu(II) and Zn(II) complexes



Scheme 3b: Synthesis of Ag(I) complex

FT-IR spectra of the free ligand showed different bands with different intensities in the range of 3043-3088 cm^{-1}. These bands are assigned to ν(C–$H_{aromatic}$) and benzimidazole ring vibrations, while, the δ(C-$H_{aromatic}$) appeared in the range 800-640 cm^{-1}. The peaks in the range 2883-2947 cm^{-1} are belongs to the CHaliphatic. The aromatic C=C is appeared at 1492-1600 cm^{-1}. The bands in the range 738-798 cm^{-1} belong to the ortho disubstituted benzene. Last but not least, a very important peak of medium intensity at 1497 cm^{-1}, is assigned to the vibration of ν(C=N) in benzimidazole.

Significantly, most of the bands that appeared in ligand spectrum appeared in complexes spectra, but in different shapes, intensities and position. The most important one is ν(C=N) in benzimidazole. This band is shifted to lower frequencies by 32-36 cm^{-1} for all complexes. These observations indicating the coordination of the tertiary nitrogen in the ligand with the metal ion [15,20,33]. The prepared ligand displayed ^{1}H NMR and ^{13}C NMR spectra consistent with its assigned symmetrical structure. In the ^{1}H NMR spectrum, the multiplet signal at δ 1.77 is attributed to the protons of (-CH_2-) group.

The protons of (-CH_2-N) group appeared at δ 4.25 as triplet signal. The protons of the fused aromatic benzene ring appeared in the range of δ 7.17-7.64. The signal of (NCHN) proton appeared as a singlet at δ 8.20. In the ^{13}C NMR spectrum, the signals at δ 26.73 and δ 43.49 are attributed to the carbon of (CH_2) and (CH_2-N), respectively. The signals at δ 110.33, 119.42, 121.42, 122.22, 133.71 and 143.39 are belongs to the carbons of the benzene ring. The carbon of (NCN) group appeared at δ 143.92.

Due to the paramagnetism of Mn(II), Co(II), Ni(II) and Cu(II) complexes, no NMR spectra have been done for them. In Zn(II) and Ag(I) complexes, the proton at position 2 in benzimidazole (NCHN) was appeared at δ 8.42 and δ 8.43, respectively. In the same time, the carbon signal at position 2 was appeared at δ 144.45 and δ 144.48, respectively. This downfield shifting was reported as a characteristic signal for coordination of benzimidazoles with metal ions [20,33]. The UV-visible spectrum of the free ligand showed two peaks, the first one at λ_{max} = 220 nm, while the second was at λ_{max} = 270 nm.

These peaks belong to n→π* and π→π* transitions of benzimidazole. In the complexes, generally, the mentioned peaks were shifted to a higher wavelength. Further, in all complexes, these peaks were either broaden or split in comparing with the ligand spectrum. All the mentioned observations were evidence for complexation of the metal. The d→d transitions for some complexes were shown clearly in different regions.

In Co(II) complex, the d→d transition is appeared overlapped with charge transfer transition as a broad peak centered at λ_{max} = 550 nm. In Ni(II) complex, it is appeared as a broad peak centered at λ_{max} = 410 nm. In Cu(II) complex, the d→d transitions are appeared as a strong band in the range 300-380 nm.

Structural Study

The 3D polymeric structure of Ag(I) complex was further confirmed by single crystal X-ray diffraction technique. Single crystal of of composition [$Ag_2(C_{18}H_{18}N_4)_3$]. 2(NO_3). 2(C_2H_6OS).H_2O) suitable for X-ray diffraction studies were grown from DMSO solution at

ambient temperature. The molecular structure of the complex is shown in Figuer 1. The complex crystallizes in a triclinic space group P-1. Crystallographic data and selected bond lengths and angles are given in Tables 1 and 2, respectively. The asymmetric unit contains one Ag(I), one and a half 1,4-bis(1-benzimidazolyl)butane ligands, a DMSO solvent molecule and disordered nitrate and water. The Ag(I) is coordinated by three benzimidazolyl ligands in an approximately trigonal geometry at Ag-N distances of 2.240(3), 2.273(3) and 2.221(3) Å. For each Ag(I), all the three benzimidazole rings are twisted out of the plane, giving the unit a distorted Y-shaped, with slight pyramidal distortion from trigonal with N-Ag-N angles of 128.12(12), 112.45(12) and 115.26(12) °. There are two crystallographically distinct 1,4-bis(1-benzimidazolyl)butane ligands, one with the benzimidazolyl groups in a *cis* arrangement and the other lying on an inversion center with benzimidazolyl groups *trans*. These ligands bridge between Ag(I) centers at Ag···Ag distances 13.78 and 14.10 Å respectively. A 3-connected ladder structure of 4^2 topology is formed, Figure 2. Crystal packing is shown in Figure 3, where the $[Ag_2(C_{18}H_{18}N_4)_3]_\infty^{2+}$ ladders pack to form small channels that are occupied by DMSO, water and the disordered NO_3^- anions.

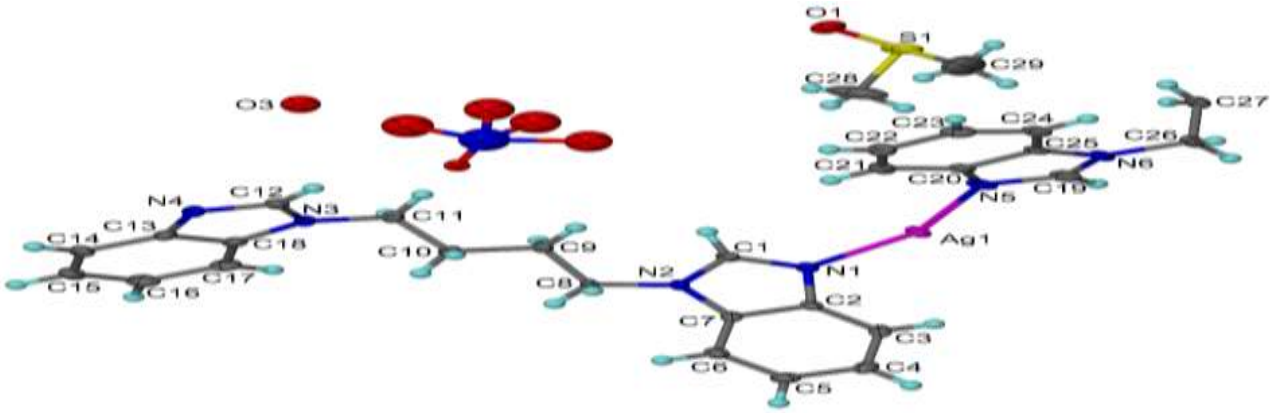


Figure 1: Asymmetric unit of Ag(I) complex at 50% ellipsoid probability, disordered nitrate and water molecules were refined isotropically

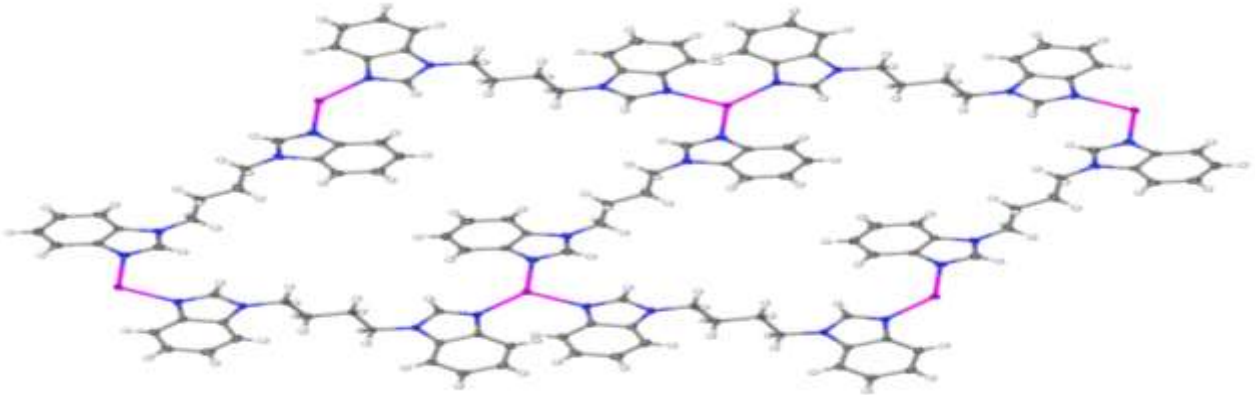


Figure 2: A 3-connected ladder structure of 4^2 topology

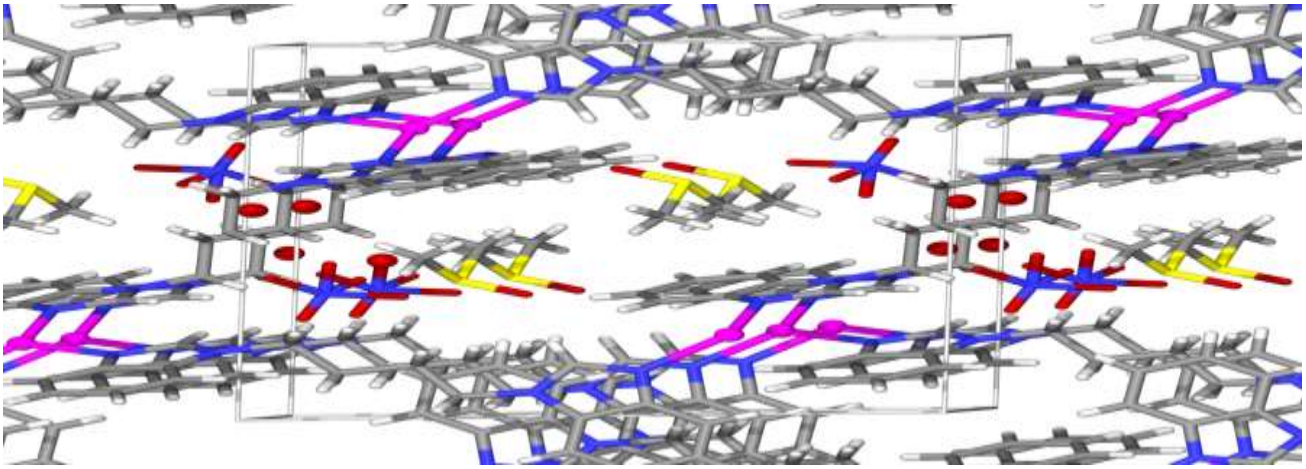


Figure 3: Crystal unit cell packing of Ag(I) complex a axis view

Table 1: Crystal data and structure refinement of Ag(I) complex

Moiety formula	0.25($C_{54}H_{54}Ag_2N_{12}$), 0.5(C_2H_6OS), 0.5(NO_3), 0.5(H_2O)
Moiety formula Weight	367.18
Crystal System	Triclinic
Space group	P-1
a, b, c [Å]	7.0113(2), 13.7850(4), 15.4155(4)
α, β, γ [°]	87.099(2), 89.510(2), 83.780(2)
V [Å^3]	1479.24(7)
Z	4
D_{calc} g/cm^3	1.649
Mu(MoKa) [/mm]	0.808
F(000)	720
T (K)	120
Radiation [Å]	MoKa 0.71073
Theta Min-Max [°]	1.49, 26.26
Nref, Npar	5578, 393
R, wR2, S	0.0486, 0.1324, 1.017

Table 2: Selected bond lengths (Å) and angles (°) for Ag(I) complex

Bond lengths			
Ag1-N1	2.240 (3)	N13-C13	1.348 (5)
Ag1-N4	2.273 (3)	N13-C55	1.463 (5)
Ag1-N2AA	2.221 (3)	N13-C53	1.376 (5)
N1-C9	1.392 (5)	O1-N1AA	1.165 (7)
N1-C13	1.316 (5)	O2-N1AA	1.140 (13)
N4-C5	1.321 (5)	O1AA-N1AA	1.177 (10)
N4-C18	1.396 (5)		
Bond Angles ( )			
N1-Ag1-N2AA	128.12 (12)	Ag1-N4-C18	123.6 (2)
N1-Ag1-N4	112.45 (12)	N1-C13-N13	113.4 (4)
N4-Ag1-N2AA	115.26 (12)	N4-C5-N0AA	114.0 (3)
Ag1-N1-C9	130.1 (3)	O1-N1AA-O2	121.7 (9)
Ag1-N1-C13	120.7 (3)	O1-N1AA-O1AA	121.4 (13)
Ag1-N4-C5	131.1 (3)	O2-N1AA-O1AA	116.9 (13)

Antibacterial Activity

The antibacterial activities of the prepared ligand and its metal complexes were evaluated against *E. coli* (ATCC 25922), environmental *Bacillus* sp. and 16 Gram-positive and Gram-negative clinical bacterial isolates using different concentrations and amikacin as a standard antibiotic. The antibacterial activity of the tested compounds was described by the minimum inhibitory concentration (MIC) method.

Generally, all the tested compounds except Zn(II) complex showed an activity against the tested bacteria (Table 3). The results showed that the ligand and its Mn(II), Co(II), Ni(II) and Cu(II) complexes exhibited low activity (MIC = 500 µg/ml-1 mg/ml) against the standard *E. coli* (ATCC 25922) and other tested bacteria. Whereas, the activity of Ag(I) complex was significantly higher than other complexes.

This is may be attributed to the releasing of Ag(I) ion from the complex, better-preventing infection and promote healing [29,37,38]. For silver complex, *E. coli* ATCC 25922 showed the highest susceptibility (MIC = 15.725 µg/ml). In addition, clinical isolates of Gram-negative bacteria were more susceptible (MIC = 62.5-250 µg/ml) than Gram-positive bacteria (MIC = 125-250 µg/ml). These results were consistent with those in previous studies [39,40], which reasoned that this was possibly due to the thickness of the peptidoglycan layer which may prevent the action of the silver ions through the bacterial cell wall. Another study considered that S. aureus has a stronger defense system against silver ion because of its thick cell wall, as well as the higher negative charge on the surface of Gram-negative bacteria.

This makes it more possible to interact with the silver positive ion and exert its antibacterial activity to higher extent compared to the Gram-positive bacteria [41]. Bacterial susceptibility to silver is genetically controlled and depends on the levels of intracellular silver uptake and its ability to interact and irreversibly denature key enzyme systems [42-44].

Silver ion has a multifaceted mode of action and multi-target sites inside the bacteria, that is why it is difficult for the bacteria to develop resistance to the broad and unspecific antibacterial activity of silver ion [41,44]. Among its targets are key enzyme systems, bacterial cell membrane, cell wall and cell growth and nucleic acids [40-45].

More importantly, silver exhibits low toxicity in the human body, and minimal risk is expected due to clinical exposure by inhalation, ingestion, dermal application or through the urological or hematogenous route [42-44].

Table 3: Antibacterial activity (µg/ml) of the tested compounds against clinical bacterial isolates

Bacterial isolate	MIC (µg/ml)							
	Ligand	Mn(II)	Co(II)	Ni(II)	Cu(II)	Zn(II)	Ag(I)	AK
E. coli ATCC 25922	500	500	500	500	500	-	15.62	3.90
E. coli (H27)	500	500	500	500	500	-	62.5	31.25
E. coli (H26)	500	500	500	500	500	-	125	62.5
E. coli (37)	500	500	500	500	500	-	62.5	ND
E. coli (39)	500	500	500	500	500	-	62.5	ND
K. pneumoniae (S1)	500	500	500	500	500	-	62.5	ND
K. pneumoniae (H32)	500	500	500	500	500	-	62.5	31.25
P. mirabilis (S2)	500	500	500	500	500	-	62.5	ND
P. mirabilis (H21)	500	500	500	500	500	-	250	125
S. enterica (Z)	500	500	500	500	500	-	62.5	ND
S. enterica (HZ)	500	500	500	500	500	-	62.5	15.6
S. enterica (B)	500	500	500	500	500	-	62.5	ND
P. aeruginosa (H25)	500	500	500	500	500	-	250	ND
P. aeruginosa (H29)	500	500	500	500	500	-	62.5	62.5
P. aeruginosa (PHZ1)	500	500	500	500	500	-	125	31.25
S. aureus (S3)	500	500	500	500	500	-	125	62.5
S. aureus (H20)	1 mg	1 mg	500	500	1mg	1mg	250	15.6
Bacillus sp. (E)	500	500	500	1mg	1mg	-	62.5	-

AK: amikacin; - = inactive, ND: not determined.

Conclusion

New series of some transition metal complexes of the ligand 1,4-bis(1-benzimidazolyl) butane have been synthesized and characterized using different techniques. According to the results obtained in this study and the literature, the polymeric structure was proposed for the prepared complexes. Furthermore, the molecular structures of Ag(I) complex was structurally determined using single-crystal X-ray diffraction techniques. The antibacterial activity of the ligand and its metal complexes were determined against *E. coli* (ATCC 25922), environmental *Bacillus* sp. and 16 clinical bacterial isolates (both Gram-positive and Gram-negative bacteria) using amikacin as a standard antibiotic. In general, Ag(I) complex has the highest activity against all the tested organisms in comparison with the other compounds.

Supplementary Materials

CCDC 1585452 contains the supplementary crystallographic data for Ag(I) complex. These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html, or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or e-mail: deposit@ccdc.cam.ac.uk.

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