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Synthesis and Biologically Relevant Silver(I)–*N*-Heterocyclic Carbene Complexes

Mohammed Z. Ghadhyeb[1], Zaman Abdalhussein Ibadi Alaridhee[2], Muhand Dohan Abid[3]

[1]Department of Chemistry, Faculty of Science, University of Kufa, Najaf, Iraq.
[2]College of Pharmacy, Islamic University, Najaf, Iraq.
[3]Ministry of Education, The General Directorate of Educational in Najaf Al-Ashraf, Najaf, Iraq.

Abstract— Synthesis and antibacterial activity studies of four substituted silver(I)-*N*-Heterocyclic carbene complexes of type [(NHC)2-Ag]Cl_2 and their respective (ligands) benzimidazolium salts (6–9) are described herein. The azolium and Ag-NHC analogues were confirmed by H^1 and C^{13}-NMR spectroscopy. The synthesized analogues were biologically characterized for *in vitro*antibacterial activity estimated against some bacteria strains *S. aureus.*and *E.coli.*

Keywords: Ag(I)–carbene complex, Benzimidazole, Ligands,*N*-Heterocyclic carbene, Antimicrobial agents.

Introduction

N-heterocyclic carbene (NHC) silver(I) complexes are commonly utilized organometallics in current inorganic preparation and bioorganometallic chemistry for the creation of various metal NHC complexes [1-3].Because of their involvement in catalysis and biology/pharmacology, NHC complexes of late transition metal complexes have gotten a lot of interest in the recent decade [4-8].Almost all transition metals and complexes have been coupled with NHCs for catalytic and biological applications [9-12]. Because of its long history of use in antimicrobial medications to treat various types of infectious disorders, silver has been a metal of interest in medicinal research [13-16].Ag(I)-NHC complexes have been produced widely among all metals and NHC complexes owing to these criteria [17]. Due to the rapid release of Ag+ ions, the benefits of silver containing metallodrugs were restricted. NHC, which strongly interacts with Ag(I), releases Ag+ at a slower pace than ionic Ag(I) complexes, provides a solution to this problem. The efficacy of silver containing metallodrugs is improved by this gradual release [18].Antitumor activity has been reported for mono and di-NHC Ag(I) complexes generated from imidazole and benzimidazole with various substitution patterns and connecting units [19]. When compared to mononuclear Ag(I)-NHC complexes, dinuclear Ag(I)-NHC complexes demonstrated superior activity against various cancer cell lines [20]. The effect of chain length on the toxicity of imidazolium and benzimidazolium salts on several cancer cell lines has also been studied [21,22].In previous research on the antimicrobial activity of Ag(I), it was discovered that the Ag(I)-NHC complexes release Ag+, which binds to the bacterial cell surface and interacts with the protein involved in cell wall formation, disrupting cell functions [23-25]. This

antibacterial effect was thought to be based on the ease with which Ag+ could be displaced from the ligand [26]. Because of the rapid release of Ag+ ions, ionic Ag(I) complexes lose their anticancer action quickly [1,2].However, because NHCs are strong donating and weak accepting ligands, and release Ag+ ions slowly, the inclusion of Ag(I) in complexation with NHC resolves the rapid release of Ag+ from the ligands [6]. The number of Ag(I) centres and NHC ligands per complex have received more attention, but the type of the substitution pattern on the ligand that would enable the complex reach the required site has received less attention. The goal of this study was to see how a periodic variation in chain length impacts the anticancer potential of binuclear Ag(I)-NHC complexes.All of the proligands were examined separately, in addition to their Ag(I) complexes, to see if the proligands alone contributed to cytotoxicity. In addition, an in vivo acute oral toxicity study was conducted to determine the safe dose of these chemicals.

Experimental

All solvents and chemicals were of the highest analytical grade and were purchased commercially. The FT-IR spectrophotometer was used to record the infrared spectra (FTIR-8400s, Shimadzu). At room temperature, Bruker 300 MHz spectrometers were used to record nuclear magnetic resonance (NMR) spectra. Bruker spectrometer model (300 MHz for 1HNMR and 75 MHz for ^{13}CNMR) was used to measure ^{1}H and ^{13}C NMR spectroscopy (DMSO-d6).

Synthesis *N,N′*-(methylenebis(4,1-phenylene))bis(2-chloroacetamide)

N,N′-(1,4-phenylene)bis(2-chloroacetamide)(**1**)was synthesized by (15 mmol) of 4,4'-methylenedianilinehas been dissolved in the DCM (20 mL then trimethylamine was added (1.5 mL). The mixture was stirred for 20 min before the chloroacetyl chloride (**1:2**) (30 mmol) was added dropwise at below 10℃then the mixture was stirred for 30 min. After completing the reaction, filter and wash extensively with distilled water, and then recrystallize using ethanol.

***N,N'-([1,1'-biphenyl]-4,4'-diyl)bis(2-chloroacetamide)* (1):** It was prepared as a fine white powder (89 % yield), (m.p.:267-269 ℃), FT-IR cm^{-1}: 3258(N-H),3090(C-H$_{aromatic}$), 2947(C-H$_{aliph}$), 2855(C-H$_{aliph}$), 1662(N-carbonyl), 1508(C=N), 1229 (C-N). ^{1}H NMR (300 MHz, DMSO-d_6) δ 10.12 (s, 1H, Ar-NH), 7.57-7.24 (m, 8H, Ar-H), 4.37 (s, 2H, -NH-CH$_2$), 3.87 (s, 2H, ph-CH$_2$-ph).

Synthesis *N*-Substituted Benzimidazole

(15 mmol) benzimidazole dissolved in 20 mL of DMSO, NaOH (20 mmol) was added after grind. The mixture was stirred for 2 hours at 90℃. The temperature has been lowered to 30°C and then 1-bromoalkane(20 mmol) was added dropwise and the temperature was raised to 40℃ for 1 hr. The product poured into 10 mL distilled water and extracted with Petroleum ether (3X10 mL). It was filtered, left the Petroleum ether was removed.

***1-decyl-1H-benzo[d]imidazole*(2):**It was prepared as a Clear yellow (81 % yield), FT-IR cm^{-1}: 3050(C-H$_{aromatic}$), 2920(C-H$_{aliph}$), 2853(C-H$_{aliph}$), 1558 (C=N),1252(C-N).^{1}H NMR (301

MHz, DMSO-d_6) δ 8.25 (s, 1H, NCHN), 7.68 -7.22 (m,4H, Ar-H), 4.21 (t, J = 7.0 Hz, 2H, N-CH_2), 1.76 (p, J = 6.9 Hz, 2H), 1.18-1.25 (m, 14H, 7 x CH_2), 0.83 (t, J = 6.7 Hz, 3H, CH_3), ^{13}C NMR (76 MHz, DMSO-d_6) δ 144.36(NCHN), 143.91, 134.22, 122.55, 122.14, 121.74, 119.85, 115.73, 110.70(Ar-C),44.54(N-CH_2), 31.78, 29.87, 29.44, 29.42, 29.19, 29.04, 26.60, 22.59(8-CH_2), 14.34(CH_3).

1-dodecyl-1H-benzo[d]imidazole **(3):** It was prepared as a Clear yellow (79 %), FT-IR cm^{-1}: 3052(C-$H_{aromatic}$),2919(C-H_{aliph}),, 2852(C-H_{aliph}), 1686 (C =N),1277 (C-N).^{1}H NMR (301 MHz, DMSO-d_6) δ 8.23 (s, 1H, NCHN), 7.73-7.21 (m, 4H,Ar-H), 4.20 (t, J = 7.0 Hz, 2H, N-CH_2), 1.76 (p, J = 6.8 Hz, 2H), 1.18-1.26(m, 16H, 9 x CH_2), 0.83 (t, J = 6.6 Hz, 3H), ^{13}C NMR (76 MHz, DMSO-d_6) δ 144.34(NCHN), 144.04, 134.25, 122.51, 121.69, 119.90, 110.63(Ar-C),44.52(N-CH_2), 31.79, 29.89, 29.43, 29.19, 29.05, 26.62, 22.59(10-CH_2), 14.32(CH_3).

1-tetradecyl-1H-benzo[d]imidazole **(4):**It was prepared as a Clear yellow (86 % yield), FT-IR cm^{-1}: 3053(C-$H_{aromatic}$), 2920(C-H_{aliph}), 2853(C-H_{aliph}), 1617 (C=N),1252 (C-N).^{1}H NMR (301 MHz, DMSO-d_6) δ 8.22 (s, 1H, NCHN), 7.66-7.13 (m, 4H, Ar-H), 4.21 (t, J = 7.1 Hz, 2H, N-CH_2), 1.76 (p, J = 7.0 Hz, 2H), 1.20-0.96 (m, 22H, 11x CH_2), 0.83 (t, J = 6.4 Hz, 3H),^{13}C NMR (76 MHz, DMSO-d6) δ 144.36(NCHN), 143.91, 134.21, 122.55, 121.74, 119.86, 110.68(Ar-C), 44.52(N-CH_2), 31.81, 29.86, 29.57, 29.54, 29.51, 29.44, 29.42, 29.24, 29.02, 26.59, 22.59(12-CH_2), 14.35(CH_3).

1-hexadecyl-1H-benzo[d]imidazole **(5):** It was prepared as a Clear yellow (85 % yield), FT-IR cm^{-1}: 3053(C-$H_{aromatic}$),2921(C-H_{aliph}), 2854(C-H_{aliph}), 1616 (C =N),1250 (C-N).^{1}H NMR (301 MHz, DMSO-d_6) δ 8.24 (s, 1H, NCHN), 7.71–7.15 (m, 4H, Ar-H), 4.25 (t, J = 7.1 Hz, 2H, N-CH_2), 3.40 (s, 2H), 2.56 (s, 1H), 1.84-1.78(p, J = 7.0 Hz, 2H), 1.25-1.20(m, 26H, 13x CH_2), 0.87(t, J = 6.5 Hz, 3H),^{13}C NMR (76 MHz, DMSO-d6) δ 144.44(NCHN), 143.93, 134.24, 122.58, 121.76, 119.88, 110.78(Ar-C), 44.51(N-CH_2), 31.79, 31.79, 29.84, 29.70, 29.53, 29.51, 29.40, 29.33, 29.21, 29.14, 28.99, 26.58, 26.57, 22.59(14-CH_2), 14.41(CH_3).

Synthesis of 1,3-disubstituted benzimidazolium salts (6,7,8 and 9)

All the 1,3-disubstituted benzimidazolium salts (6,7,8 and 9) were synthesized according to the reported procedures. [22] (20 mmol)*N*-substituted benzimidazole (2,3,4 and 5) in 10 mL of dioxane was placed in a 50 mL round bottom flask. (10 mmol)of*N,N′*-(1,4-phenylene)bis(2-chloroacetamide)(**1**) was added onto the mixture. The mixture was refluxed at 90 ^{o}C for 24 hrs. After the completion of reaction, the solvent was evaporated then recrystallized using methanol.

6: It was prepared as a powder (74 % yield) (m.p=130-132 °C). FT-IR cm^{-1}: 3287(N-H), 3087(C-$H_{aromatic}$), 2918(C-H_{aliph}), 2851(C-H_{aliph}), 1668(N-carbonyl), 1234 (C-N). ^{1}H NMR (300 MHz, DMSO-d6) δ, ppm: 10.12 (s, 1H, Ar-NH), 9.84 (s, 1H, NCHN), 7.57-7.24 (m, 8H, Ar-H), 4.96 (t, J = 6.3 Hz, 2H, N-CH2), 4.37 (s, 2H, -NH-CH_2), 3.87 (s, 2H, ph-CH_2-ph), 1.76 (p, J = 6.5 Hz, 2H, CH2), 1.25 – 1.33 (m, 22H,CH2), 0.91 (m, 3H,CH3), ^{13}C NMR (75 MHz, DMSO-d6) δ 169.93, 137.89(NCHN), 137.63, 137.35, 136.07, 134.90, 129.65, 125.22,

124.93, 120.95, 105.22, 104.73, 72.45, 52.73, 50.65, 39.99, 31.85, 29.85, 29.49, 29.45, 28.86, 27.16, 27.13, 22.74, 14.10.

7: It was prepared as a powder (71 % yield) (m.p=144-146 ℃), FT-IR cm^{-1}: 3261(N-H),3099(C-$H_{aromatic}$), 2919(C-H_{aliph}), 2852 (C-H_{aliph}), 1664(N-carbonyl), 1248 (C-N). ^{1}H NMR (300 MHz, DMSO-d6) δ, ppm: 10.12 (s, 1H, Ar-NH), 9.84 (s, 1H, NCHN), 7.57-7.24 (m, 8H, Ar-H), 4.96 (t, J = 6.3 Hz, 2H, N-CH2), 4.37 (s, 2H, -NH-CH_2), 3.87 (s, 2H, ph-CH_2-ph), 1.76 (p, J = 6.5 Hz, 2H, CH2), 1.25 – 1.33 (m, 22H,CH2), 0.91 (m, 3H,CH3), ^{13}C NMR (75 MHz, DMSO-d6) δ 169.93, 137.89(NCHN), 137.63, 137.35, 136.07, 134.90, 129.65, 125.22, 124.93, 120.95, 105.22, 104.73, 72.45, 52.73, 50.65, 39.99, 31.85, 29.85, 29.49, 29.45, 28.86, 27.16, 27.13, 22.74, 14.10.

8: It was prepared as a powder (81 % yield) (m.p=171-173 ℃),FT-IR cm^{-1}: 3288(N-H), 3087(C-$H_{aromatic}$), 2920(C-H_{aliph}), 2853 (C-H_{aliph}), 1660(N-carbonyl), 1232 (C-N). ^{1}H NMR (300 MHz, DMSO-d6) δ, ppm: 10.12 (s, 1H, Ar-NH), 9.84 (s, 1H, NCHN), 7.57-7.24 (m, 8H, Ar-H), 4.96 (t, J = 6.3 Hz, 2H, N-CH2), 4.37 (s, 2H, -NH-CH_2), 3.87 (s, 2H, ph-CH_2-ph), 1.76 (p, J = 6.5 Hz, 2H, CH2), 1.25 – 1.33 (m, 22H,CH2), 0.91 (m, 3H,CH3), ^{13}C NMR (75 MHz, DMSO-d6) δ 169.93, 137.89(NCHN), 137.63, 137.35, 136.07, 134.90, 129.65, 125.22, 124.93, 120.95, 105.22, 104.73, 72.45, 52.73, 50.65, 39.99, 31.85, 29.85, 29.49, 29.45, 28.86, 27.16, 27.13, 22.74, 14.10.

9: It was prepared as a powder (83 % yield) (m.p=187-189 ℃), FT-IR cm^{-1}: 3243(N-H), 3054(C-$H_{aromatic}$), 2921(C-H_{aliph}), 2854 (C-H_{aliph}), 1617(N-carbonyl), 1252 (C-N). ^{1}H NMR (300 MHz, DMSO-d6) δ, ppm: 10.12 (s, 1H, Ar-NH), 9.84 (s, 1H, NCHN), 7.57-7.24 (m, 8H, Ar-H), 4.96 (t, J = 6.3 Hz, 2H, N-CH2), 4.37 (s, 2H, -NH-CH_2), 3.87 (s, 2H, ph-CH_2-ph), 1.76 (p, J = 6.5 Hz, 2H, CH2), 1.25 – 1.33 (m, 22H,CH2),0.91 (m, 3H,CH_3), ^{13}C NMR (75 MHz, DMSO-d6) δ 169.93, 137.89(NCHN),137.63, 137.35, 136.07, 134.90, 129.65, 125.22, 124.93, 120.95, 105.22, 104.73, 72.45, 52.73, 50.65, 39.99, 31.85, 29.85, 29.49, 29.45, 28.86, 27.16, 27.13, 22.74, 14.10.

Synthesisof silver(I)−*N*HC complexes(10,11,12 and 13)
Silver oxide (2 mmol) added to 1,3-disubstituted benzimidazolium salts (6,7,8 and 9) solution (1 mmol) and dissolved in 20 mL acetonitrile. Stirred the mixture for 8-10 h in glassware, covered by aluminum foil. Then filtration of the black suspension via the celite to remove the excess Ag_2O, then removed the solvent using a rotary evaporator.

10: It was prepared as a solid product (73 % yield) (m.p = 221-223 ℃). FT-IR cm^{-1}: 3252(N-H),3054(C-$H_{aromatic}$), 2921(C-H_{aliph}), 2855(C-H_{aliph}), 1665(N-carbonyl), 1258 (C-N). ^{1}H NMR (300 MHz, DMSO-d_6) δ, ppm:10.05 (s, 2H,Ar-NH), 7.40-7.01 (s, 16H,Ar-H), 4.54 (s, 4H, carbonyl-CH_2-N), 3.71 (t, J = 6.4 Hz, 4H, N-CH_2), 1.99-1.83 (p, J = 6.6 Hz, 4H,CH_2), 1.39–1.21 (m, 36H,CH_2), 0.94 (t, J = 6.2 Hz, 6H,CH_3). ^{13}C NMR (75 MHz, DMSO-d_6) δ,ppm: 185.98(C-Ag),165.78(C=O), 161.95(Ar-C-N), 133.09,127.34,126.61, 123.43,121.93 (Ar-C),125.13, 123.17,56.76 (carbonyl -CH_2-N), 54.29(N-CH_2-),40.41, 40.21, 40.09,39.76,39.56,

39.12,33.76, 31.94, 31.39, 29.76, 29.56,29.34,29.23, 28.78, 27.41,24.96, 23.67,22.97(-CH_2),12.98(-CH_3)

11: It was prepared as a solid product (68 % yield) (m.p = 188-190 °C). FT-IR cm^{-1}: 3266(N-H), 3097(C-Haromatic), 2922(C-Haliph), 2851(C-Haliph), 1673(N-carbonyl), 1249 (C-N). ^{1}H NMR (300 MHz, DMSO-d_6) δ, ppm: 10.08 (s, 2H,Ar-NH), 7.41-6.99 (s, 16H, Ar-H), 4.50 (s, 4H, carbonyl-CH_2-N), 3.75(t, J = 6.4 Hz, 4H, N-CH_2), 1.92-1.82 (p, J = 6.6 Hz, 4H,CH_2), 1.40–1.20 (m, 36H,CH_2), 0.95 (t, J = 6.2 Hz, 6H,CH_3).
^{13}C NMR (75 MHz, DMSO-d_6) δ, ppm: 185.84(C-Ag),164.87(C=O), 161.66(Ar-C-N), 132.87,129.04,127.74,123.78, 122.89 (Ar-C),124.51, 123.24,55.89 (carbonyl-CH_2-N), 54.51(N-CH_2-),41.08, 40.68, 40.01, 39.86,39.46, 39.22,33.78, 31.82, 31.24, 29.65, 29.47,29.31,29.21, 28.89, 28.38, 27.35,27.13,24.78, 23.64,22.75(-CH_2),12.87(-CH_3)

12: It was prepared as a solid product (74 % yield) (m.p = 204-206 °C), FT-IR cm^{-1}: 3253(N-H), 3117(C-Haromatic), 2921(C-Haliph), 2851(C-Haliph), 1673(N-carbonyl), 1251 (C-N). ^{1}H NMR (300 MHz, DMSO-d_6) δ, ppm: 10.09 (s, 2H,Ar-NH), 7.41-7.12 (s, 16H, Ar-H), 4.58 (s, 4H, carbonyl-CH_2-N), 3.73(t, J = 6.4 Hz, 4H, N-CH_2), 1.98-1.82 (p, J = 6.6 Hz, 4H,CH_2), 1.40–1.22 (m, 36H,CH_2), 0.97 (t, J = 6.2 Hz, 6H,CH_3).
^{13}C NMR (75 MHz, DMSO-d_6) δ, ppm: 185.14(C-Ag),164.65(C=O), 161.27(Ar-C-N), 133.44,130.48,127.25,123.47, 122.21 (Ar-C),124.24, 123.08, 55.28 (carbonyl-CH_2-N), 54.74(N-CH_2-),41.78, 40.17, 40.08, 39.98,39.27, 38.81,33.45, 31.57, 30.84, 29.78, 29.54,29.11,28.88, 28.49, 28.18,27.89,27.46,27.13,24.95, 23.47,22.70(-CH_2),12.17(-CH_3)

13: It was prepared as a solid product (71 % yield) (m.p = 235-237 °C), FT-IR cm^{-1}: 3254(N-H), 3088(C-Haromatic), 2989(C-Haliph), 2851(C-Haliph), 1661(N-carbonyl), 1237 (C-N). ^{1}H NMR (300 MHz, DMSO-d_6) δ, ppm: 10.02 (s, 2H,Ar-NH), 7.39-7.09 (s, 16H, Ar-H), 4.52 (s, 4H, carbonyl-CH_2-N), 3.70(t, J = 6.4 Hz, 4H, N-CH_2), 1.98-1.80 (p, J = 6.6 Hz, 4H,CH_2), 1.36–1.19 (m, 36H,CH_2), 0.94 (t, J = 6.2 Hz, 6H,CH_3).
^{13}C NMR (75 MHz, DMSO-d_6) δ, ppm: 186.11(C-Ag),165.15(C=O), 161.07(Ar-C-N), 134.41,131.74,128.58,123.68, 122.45 (Ar-C),124.38, 123.13, 55.57 (carbonyl-CH_2-N), 55.34(N-CH_2-),42.14, 40.84, 40.18, 39.92,39.37, 38.71,33.84, 31.87, 31.80, 29.97, 29.61,29.02,28.78, 28.61, 28.47, 28.27,27.94, 27.63,27.41,27.11,24.91,23.54,22.71(-CH_2) ,12.35(-CH_3).

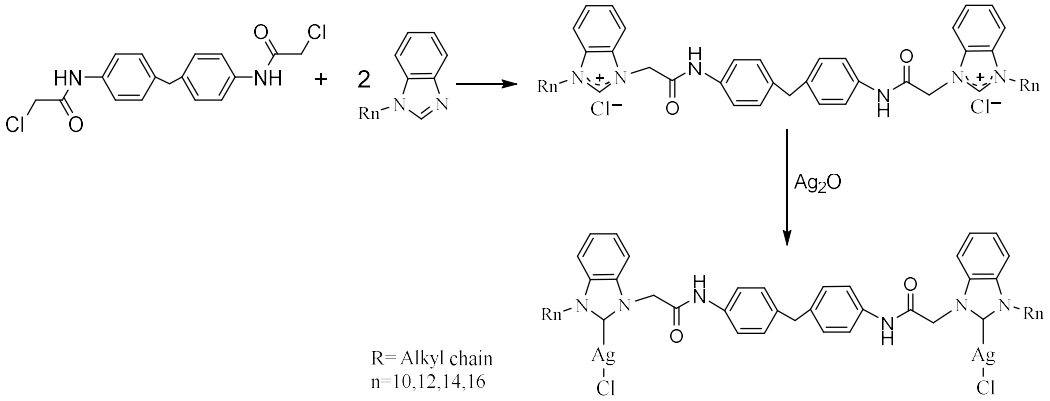
Antibacterial activity test

By measuring the inhibitory zone in Muller Hinton agar, ligands (7 and 9) and complexes (11 and 13) were evaluated for antibacterial activity against Staphylococcus aureus and Escherichia coli (6mm). The standard drug for antibacterial activity was azithromycin (100,200) g/mL. By dipping a cotton swab in the solution and streaking across the surface of the agar plates, each bacteria isolate was inoculated on Muller- Hinton Agar [sterilize in autoclave]. Then four holes were drilled in the cemented material (6 mm).These holes were filled with (0.5 mL) of the produced compounds (100,200) g/ mL diluted in 1 mL of DMSO solvent). After 24 hours of incubation at 37 °C, the zone inhibition was evaluated [27].

Results and discussion

Synthesis and characterization

The NHC precursors 1–9 were synthesized using a modified technique [28], which included a change in solvent and reaction duration. The reaction was carried out in 1,4-dioxane by refluxing the corresponding n-alkyl benzimidazole with 1,4-dibromobutane in a 2:1 mole ratio. (scheme 1)



Scheme 1: Synthesis of bis-benzeimidazolium salt and its complexes

The product 1,3-disubstituted benzimidazolium salts (6,7,8, and 9) precipitated from hot dioxane, yielding thick sparkling flaky precipitates in medium to high yield after cooling to room temperature. All of these salts are air and moisture stable, and they are soluble in polar organic solvents including methanol, ethanol, DMSO, and acetonitrile, but in dioxane, diethylether, petroleum ether, and water they are nearly insoluble. As previously described [24], the Ag(I) complexes were made by in situ deprotonation of 1,3-disubstituted benzimidazolium salts (6,7,8, and 9) with Ag2O in a bi-ratio. After filtration to remove the insoluble AgCl. All of these complexes are soluble in acetonitrile and DMSO, but in methanol, ethanol, diethylether, petroleum ether, and water, they are nearly insoluble. A combination of IR, 1 H, and 13C-NMR was used to determine the structures of 1-8 and their respective Ag(I) complexes (9-16).

FTIR analysis

Because the compounds contain organic functional groups as well as alkyl chains other than benzimidazolium centres, strong peaks in the functional group area were expected. Because the terminal alkyl chain lengths of all the salts and silver(I) complexes differ, the major absorptions are attributed to (=C-H) medium to low intensity stretching vibrations at 3100-3000 cm-1 and (-C-H) aliphatic stretching vibrations of great intensity from 2990-2820 cm-1. The (C=C) aromatic ring stretches have medium absorptions ranging from 1600 to 1400 cm-1. Between 1600-1500 cm-1, the (C=N) stretches produce strong and acute absorptions, whereas the (C-N) stretches produce medium to weak bands at 1260-1130 cm-1 [29].The respective silver(I) complexes have the same absorption bands as the salts, with a little shift to lower frequency, and a drop in absorption strength, which could be attributed to the presence of silver centres. Carbon to Ag(I) stretching vibrations are not visible in the visible spectrum because they occur in the far infrared.

^{1}H and ^{13}C NMR analysis

All of the proligands' 1H NMR spectra in DMSO-d6 showed the predicted resonances in their respective areas. The alkyl chain protons have resonances between 0.9 and 2.0 ppm in the upfield area, while the methylene protons (–CH2-N) have resonances between 4.5 and 4.8 ppm. The acidic protons of the (NCHN), which emerged as a singlet at 12 ppm, were the most characteristic resonance considered as an indication for the synthesis of proligand. Because these acidic protons are eliminated during ligand conversion, there is no resonance in the downfield area about 12 ppm in any NHCAg(I) complex spectra. Aromatic protons are found in the 7.5-7.0 ppm range. N-H of amide, on the other hand, appears over 10.0 ppm.Other protons have chemical shifts that are similar to those of their predecessors. Apart from the resonances of alkyl and aromatic carbons, the resonance about 137 ppm is the most distinctive in the 13C NMR spectra of proligands. The most deshielded C-2 carbons present between two nitrogens cause this resonance. All of these resonances correspond to chemical shifts observed for other benzimidazolium salts and complexes [30]. C2 is further deshielded after deprotonation and coordination to silver(I), resulting in a shift of resonance to around 185 ppm in the form of doublets. The evidence for effective complexation is in line with what has been published in the literature [31]. Lin et al. investigated and reported the lack of coupling for carbene resonances, which they attributed to the fluxional behavior of silver NHC complexes, which, if slowed on the NMR time scale, might allow observation of carbene coupling to silver [32,33].

The antibacterial activity test

Using azithromycin as a benchmark, the antibacterial activity of substituted benzoimidazolium salts and their N-heterocyclic carbene corresponding Ag(I) complexes was investigated against E. coli as a representative gram-negative bacteria and S. aureus as a gram-positive bacteria. All of the substituted benzoimidazolium salts and related Ag(I) complexes showed activity against the investigated microorganisms when compared to azithromycin. In this illustration, a representative representation of the zone of inhibition is depicted (Table 1). The antibacterial activity of (11) is the highest and exhibited good inhibition against the tested bacteria, even more than azithromycin, according to the tabulated findings. The complex has a moderate activity (13), while the ligand has a low activity (7 and 9). E. coli, on the other hand, showed the most resistance to the complex (11).As the amount of the complicated suspensions grows, the gram negative bacteria's sensitivity increases. The results for the bacteria S. aureus were almost identical to those for E. coli, as shown in (Table 1). The bactericidal activity of the ligand (7) was modest. Similarly, as the volume of the complex suspensions increases, the sensitivity of the gram positive bacteria increases. At concentrations of 100 and 200 g ml^{-1}, all other compounds had different values[34].

Table 1: Antibacterial activities of compounds 7,9,11 and 13 against *E.coli.* and *S. aureus*

Compound	***E.coli.*** **Inhibition zone (mm)**		***S. aureus*** **Inhibition zone (mm)**	
	100 µg mL^{-1}	**200 µg mL^{-1}**	**100 µg mL^{-1}**	**200 µg mL^{-1}**
7	**20**	**25**	**10**	**15**

9	**20**	**20**	**20**	**15**
11	**30**	**35**	**30**	**35**
13	**25**	**30**	**25**	**30**
AZ	**30**	**40**	**20**	**30**

Conclusion

Spectral, FT-IR, and NMR spectroscopy were used to describe a new series of bis-benzoimidazolium salts and associated bis-NHC-Ag(I) complexes. The biological activity of the bis-benzeimidazolium salt and Ag(I) complexes against microorganisms was found to be quite high.

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