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Research Article

Synthesis, Characterization, and *In Vitro* Cytotoxicity of Platinum(II) Complexes Bearing Chiral Tetradentate Salicylaldimine Ligands

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A series of platinum(II) complexes with chiral Schiff base ligands derived from various salicylaldehydes with (*R,R′*)- and (*S,S′*)-cyclohexanediamine were synthesized and characterized by ESI-MS, IR, and NMR. Obtained spectra with typical signals were in agreement with suggested molecular formulae of the complexes. Their photophysical properties were studied by UV-visible and emission spectroscopies. The UV-Vis showed the typical band with low energy at visible range 400–500 nm for MLCT, and this band can emit the luminescent band with emission maximum wavelengths at 529–595 nm. The *in vitro* cytotoxicity of obtained platinum(II) complexes was screened for KB and MCF-7 human cancer cell lines. The results showed that (*S*)-enantiomers were more active than (*R*)-enantiomers and the different positions of methoxy group in salicyl ring gave different cytotoxicities.

1. Introduction

Schiff bases are considered as a very important class of organic compounds which have been applied in many biological aspects such as antimicrobial, antifungal, and antitumor activity [1]. Their coordination with transition metals generated a great deal of relatively stable transition metal complexes which have showed interesting properties used in chemical catalysis [2–4], analysis [5–7], and advanced materials [8–10]. These coordination compounds have also exhibited wonderful biological applications including antimicrobial, antifungal, anti-inflammatory, and anticancer activity [11–15]. The medicinal properties of metal Schiff base complexes depend on the nature of metal ions and ligands. One of the life's biochemical features is chirality. Sometimes, chirality plays a decisive role in the area of pharmaceuticals, agrochemicals, flavors, and fragrances. In most cases, all the enantiomers of a chiral compound are considered as different "chemicals" and each stereoisomer is tested separately for its drug action [16]. So, chiral metal complexes have attracted the attention of many research groups. Some chiral Schiff base complexes of Ni(II), Cu(II), and Zn(II) and their DNA binding, antioxidant, and antibacterial activities were studied, and the results showed that *S*-enantiomers of the complexes were more efficient for DNA interaction, antioxidant, and antibacterial activities than their *R*-enantiomers [17, 18]. Chiral Mn(IV) complexes with Schiff base ligands were synthesized, and the interaction of the chiral Mn(IV) complexes with CT-DNA was studied, and the results showed that the complexes with (*S*)-ligands exhibited more efficient CT-DNA interaction than the complexes with (*R*)-ligands [19]. Recently, there were some studies on bioactivity of tetradentate salicylaldimine platinum(II) complexes [20–23]; however, the research number of chiral Schiff base platinum(II) complexes in this field is quite limited. In this work, we continue to study on the synthesis of a series of platinum(II) complexes with chiral tetradentate salicylaldimine ligands obtained by the reaction of (*R,R′*)-cyclohexanediamine and (*S,S′*)-cyclohexanediamine with some salicylaldehydes. Characterization of

obtained complexes was studied by ESI-MS, FT-IR, NMR, and CD spectroscopies, and their photophysical properties were studied by UV-Vis and luminescent spectra. Their *in vitro* antitumor activities are also evaluated against KB and MCF-7 human cancer cell lines.

2. Materials and Methods

Analytical reagent grade chemicals were used as received from commercial companies without further purification. All solvents were purified by following the appropriate purification procedures.

Mass spectra (m/z) were recorded on Agilent 6310 Ion Trap spectrometer. Infrared spectra (cm^{-1}) were obtained from KBr pellets using a Perkin Elmer Spectrum Two spectrophotometer. ^{1}H-NMR and ^{13}C-NMR spectra were analyzed using a Bruker Advance 500 MHz NMR spectrometer with TMS as internal standard, and chemical shifts (δ) were recorded in ppm. Optical rotations were recorded on Atago POLAX-2L polarimeter at the wavelength of measuring light 589 nm for studied ligands. CD spectra (235–400 nm) were measured on a Chirascan CD spectrometer for obtained chiral salen platinum(II) complexes.

3. Preparation of Chiral Schiff Base Ligands

Chiral Schiff base ligands were prepared similarly according to the known procedure from the condensation of (*R*,*R*′)- or (*S*,*S*′)-cyclohexanediamine with the relative salicylaldehydes [24]. Pure (*R*,*R*)-1,2-diaminonium cyclohexane mono-L-(+)-tartrate or (*S*,*S*)-1,2-diaminonium cyclohexane mono-D-(+)-tartrate (2.05 g, 7.6 mmol) and Na_2CO_3 (1.65 g, 15.5 mmol) with added methylene chloride (20 mL) and distilled water (15 mL) in a 100 ml flask were stirred for 1 h. After the mixture turned to clear solutions, relative salicylaldehyde (15.4 mmol) was added to organic layer and the new mixture was put under ultrasound for 1 h and then separated to dryness. The organic layer was dried over anhydrous Na_2SO_4, and the solvent was removed under reduced pressure to obtain a yellowish product.

3.1. N,N′-Bisalicylidene-(R,R′)-1,2-cyclohexanediamine ((R)L1H$_2$). Yellow oil product (92%), **ESI–MS** (m/z) 323.0 ($M + H^+$), $[\alpha]_D - 79$ (*c* 1.1; $CHCl_3$). **IR** (KBr, cm^{-1}): 2933 (ν, C–H), 2647 (ν, O–H), 1630 (ν, C=N), 1497 (ν, C=C), 1278 (ν, C–N), 1204 (ν, C–O), 848, 755 (δ, C–H), 663. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): δ 13.29 (s, 2H, 2OH), 8.24 (s, 2H, 2CH=N), 7.22 (dt, $J = 8.5$; 1.5, 2H, ArH), 7.13 (dd, $J = 7.5$; 1.5, 2H, ArH), 6.87 (d, $J = 8.0$, 2H, ArH), 6.78 (t, $J = 7.5$, 2H, ArH), 3.29 (m, 2H, CyH), 1.93 (m, 2H, CyH), 1.86 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.46 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): δ 164.72 (2C, C–OH), 160.99 (2C, C=N), 132.16 (2C, C_{Ar}), 131.48 (2C, C_{Ar}), 118.67 (2C, C_{Ar}), 118.60 (2C, C_{Ar}), 116.78 (2C, C_{Ar}), 72.62 (2C, C_{Cy}), 33.10 (2C, C_{Cy}), 24.18 (2C, C_{Cy}).

3.2. N,N′-Bisalicylidene-(S,S′)-1,2-cyclohexanediamine ((S)L1H$_2$). Yellow oil product (91%), **ESI–MS** (m/z) 323.0 ($M + H^+$), $[\alpha]_D + 78$ (*c* 1.1; $CHCl_3$). **IR** (KBr, cm^{-1}): 2932 (ν, C–H), 2646 (ν, O–H), 1630 (ν, C=N), 1497 (ν, C=C), 1278 (ν, C–N), 1204 (ν, C–O), 848, 755 (δ, C–H), 663. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): δ 13.30 (s, 2H, 2OH), 8.25 (s, 2H, 2CH=N), 7.23 (dt, $J = 8.5$; 1.5, 2H, ArH), 7.13 (dd, $J = 7.5$; 1.5, 2H, ArH), 6.87 (d, $J = 8.5$, 2H, ArH), 6.78 (t, $J = 7.5$, 2H, ArH), 3.30 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.87 (m, 2H, CyH), 1.73 (m, 2H, CyH), 1.47 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): δ 164.72 (2C, C–OH), 160.98 (2C, C=N), 132.16 (2C, C_{Ar}), 131.48 (2C, C_{Ar}), 118.67 (2C, C_{Ar}), 118.59 (2C, C_{Ar}), 116.77 (2C, C_{Ar}), 72.63 (2C, C_{Cy}), 33.10 (2C, C_{Cy}), 24.18 (2C, C_{Cy}).

3.3. N,N′-Bis(5-fluorosalicylidene)-(R,R′)-1,2-cyclohexanediamine ((R)L2H$_2$). Yellow solid product (93%), **ESI–MS** (m/z) 359.0 ($M + H^+$), $[\alpha]_D - 50$ (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2920 (ν, C–H), 2603 (ν, O–H), 1635 (ν, C=N), 1488 (ν, C=C), 1273 (ν, C–N), 1196 (ν, C–O), 1140, 825, 784 (δ, C–H), 677. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): δ 12.94 (s, 2H, 2OH), 8.19 (s, 2H, 2CH=N), 6.96 (dt, $J = 9.0$; 3.0, 2H, ArH), 6.84 (m, 4H, ArH), 3.32 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.89 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.48 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): δ 163.73 and 163.71 (2C, C–OH), 156.98 and 156.27 (2C, C–F), 154.39 (2C, C=N), 119.38 and 119.19 (2C, C_{Ar}), 118.32 and 118.26 (2C, C_{Ar}), 117.85 and 117.79 (2C, C_{Ar}), 116.61 and 116.43 (2C, C_{Ar}), 72.68 (2C, C_{Cy}), 32.94 (2C, C_{Cy}), 24.09 (2C, C_{Cy}).

3.4. N,N′-Bis(5-fluorosalicylidene)-(S,S′)-1,2-cyclohexanediamine ((S)L2H$_2$). Yellow solid product (94%), **ESI–MS** (m/z) 359.0 ($M + H^+$), $[\alpha]_D + 50$ (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2920 (ν, C–H), 2602 (ν, O–H), 1634 (ν, C=N), 1486 (ν, C=C), 1273 (ν, C–N), 1196 (ν, C–O), 1140, 824, 784 (δ, C–H), 676; **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): δ 12.93 (s, 2H, 2OH), 8.19 (s, 2H, 2CH=N), 6.96 (dt, $J = 9.0$; 3.0, 2H, ArH), 6.84 (m, 4H, ArH), 3.32 (m, 2H, CyH), 1.95 (m, 2H, CyH), 1.89 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.48 (m, 2H, CyH); **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): δ 163.73 and 163.71 (2C, C–OH), 157.00 and 156.29 (2C, C–F), 154.41 (2C, C=N), 119.38 and 119.20 (2C, C_{Ar}), 118.33 and 118.27 (2C, C_{Ar}), 117.86 and 117.80 (2C, C_{Ar}), 116.61 and 116.42 (2C, C_{Ar}), 72.69 (2C, C_{Cy}), 32.95 (2C, C_{Cy}), 24.10 (2C, C_{Cy}).

3.5. N,N′-Bis(3-methoxysalicylidene)-(R,R′)-1,2-cyclohexanediamine ((R)L3H$_2$). Yellow oil product (90%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D - 60$ (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2933 (ν, C–H), 2667 (ν, O–H), 1627 (ν, C=N), 1465 (ν, C=C), 1251 (ν, C–N), 1169 (ν, C–O), 1083, 839, 735 (δ, C–H), 647. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): δ 13.82 (s, 2H, 2OH), 8.24 (s, 2H, 2CH=N), 6.85 (dd, $J = 8.0$; 1.5, 2H, ArH), 6.78 (dd, $J = 8.0$; 1.5, 2H, ArH), 6.72 (t, $J = 8.0$, 2H, ArH), 3.86 (s, 6H, 2 MeO), 3.31 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.87 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.48 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): δ 164.75 (2C, C–OH), 151.62 (2C, C=N), 148.26 (2C, C–OMe), 123.19 (2C, C_{Ar}), 118.41 (2C, C_{Ar}), 117.87 (2C, C_{Ar}), 113.92 (2C,

C_{Ar}), 72.41 (2C, C_{Cy}), 56.04 (2C, MeO), 33.02 (2C, C_{Cy}), 24.05 (2C, C_{Cy}).

3.6. N,N′-Bis(3-methoxysalicylidene)-(S,S′)-1,2-cyclohexanediamine ((S)L3H$_2$). Yellow oil product (91%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ + 59 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2926 (*ν*, C–H), 2665 (*ν*, O–H), 1625 (*ν*, C=N), 1461 (*ν*, C=C), 1248 (*ν*, C–N), 1169 (*ν*, C–O), 1080, 838, 731 (*δ*, C–H), 646. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 13.82 (s, 2H, 2OH), 8.24 (s, 2H, 2CH=N), 6.85 (d, *J* = 8.0, 2H, ArH), 6.78 (d, *J* = 7.0, 2H, ArH), 6.72 (t, *J* = 8.0, 2H, ArH), 3.86 (s, 6H, 2 MeO), 3.31 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.87 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.48 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.75 (2C, C–OH), 151.61 (2C, C=N), 148.26 (2C, C–OMe), 123.19 (2C, C_{Ar}), 118.42 (2C, C_{Ar}), 117.87 (2C, C_{Ar}), 113.92 (2C, C_{Ar}), 72.41 (2C, C_{Cy}), 56.04 (2C, MeO), 33.02 (2C, C_{Cy}), 24.05 (2C, C_{Cy}).

3.7. N,N′-Bis(4-methoxysalicylidene)-(R,R′)-1,2-cyclohexanediamine ((R)L4H$_2$). Yellow oil product (92%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ − 260 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2934 (*ν*, C–H), 2666 (*ν*, O–H), 1626 (*ν*, C=N), 1514 (*ν*, C=C), 1291 (*ν*, C–N), 1223, 1165 (*ν*, C–O), 835, 799 (*δ*, C–H), 647. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 13.76 (s, 2H, 2OH), 8.08 (s, 2H, 2CH=N), 6.99 (d, *J* = 8.5, 2H, ArH), 6.35 (d, *J* = 2.5, 2H, ArH), 6.30 (dd, *J* = 8.5; 2.5, 2H, ArH), 3.76 (s, 6H, 2 MeO), 3.22 (m, 2H, CyH), 1.96 (m, 2H, CyH), 1.86 (m, 2H, CyH), 1.67 (m, 2H, CyH), 1.45 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 165.05 (2C, C–OH), 163.73 (2C, C=N), 163.49 (2C, C–OMe), 132.78 (2C, C_{Ar}), 112.22 (2C, C_{Ar}), 106.24 (2C, C_{Ar}), 101.13 (2C, C_{Ar}), 71.53 (2C, C_{Cy}), 55.30 (2C, MeO), 33.07 (2C, C_{Cy}), 24.24 (2C, C_{Cy}).

3.8. N,N′-Bis(4-methoxysalicylidene)-(S,S′)-1,2-cyclohexanediamine ((S)L4H$_2$). Yellow oil product (91%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ + 261 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2932 (*ν*, C–H), 2664 (*ν*, O–H), 1617 (*ν*, C=N), 1512 (*ν*, C=C), 1288 (*ν*, C–N), 1221, 1163 (*ν*, C–O), 832, 796 (*δ*, C–H), 645. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 13.79 (s, 2H, 2OH), 8.09 (s, 2H, 2CH=N), 6.99 (d, *J* = 8.5, 2H, ArH), 6.35 (d, *J* = 2.5, 2H, ArH), 6.30 (dd, *J* = 7.5; 2.5, 2H, ArH), 3.76 (s, 6H, 2 MeO), 3.22 (m, 2H, CyH), 1.96 (m, 2H, CyH), 1.86 (m, 2H, CyH), 1.67 (m, 2H, CyH), 1.45 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.90 (2C, C–OH), 163.74 (2C, C=N), 163.45 (2C, C–OMe), 132.75 (2C, C_{Ar}), 112.26 (2C, C_{Ar}), 106.21 (2C, C_{Ar}), 101.12 (2C, C_{Ar}), 71.60 (2C, C_{Cy}), 55.29 (2C, MeO), 33.08 (2C, C_{Cy}), 24.24 (2C, C_{Cy}).

3.9. N,N′-Bis(5-methoxysalicylidene)-(R,R′)-1,2-cyclohexanediamine ((R)L5H$_2$). Yellow solid product (92%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ − 298 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2939 (*ν*, C–H), 2581 (*ν*, O–H), 1631 (*ν*, C=N), 1492 (*ν*, C=C), 1269 (*ν*, C–N), 1161 (*ν*, C–O), 1095, 810, 785 (*δ*, C–H), 670. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 12.79 (s, 2H, 2OH), 8.19 (s, 2H, 2CH=N), 6.86 (dd, *J* = 9.0; 3.0, 2H, ArH), 6.81 (d, *J* = 9.0, 2H, ArH), 6.64 (d, *J* = 3.0, 2H, ArH), 3.70 (s, 6H, 2 MeO), 3.29 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.88 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.48 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.48 (2C, C–OH), 155.08 (2C, C=N), 151.99 (2C, C–OMe), 119.41 (2C, C_{Ar}), 118.26 (2C, C_{Ar}), 117.47 (2C, C_{Ar}), 114.87 (2C, C_{Ar}), 72.78 (2C, C_{Cy}), 55.90 (2C, MeO), 33.05 (2C, C_{Cy}), 24.17 (2C, C_{Cy}).

3.10. N,N′-Bis(5-methoxysalicylidene)-(S,S′)-1,2-cyclohexanediamine ((S)L5H$_2$). Yellow solid product (93%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ + 300 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2937 (*ν*, C–H), 2579 (*ν*, O–H), 1630 (*ν*, C=N), 1490 (*ν*, C=C), 1267 (*ν*, C–N), 1160 (*ν*, C–O), 1095, 809, 784 (*δ*, C–H), 670. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 12.80 (s, 2H, 2OH), 8.19 (s, 2H, 2CH=N), 6.85 (dd, *J* = 9.0; 3.0, 2H, ArH), 6.81 (d, *J* = 9.0, 2H, ArH), 6.64 (d, *J* = 3.0, 2H, ArH), 3.70 (s, 6H, 2 MeO), 3.29 (m, 2H, CyH), 1.94 (m, 2H, CyH), 1.88 (m, 2H, CyH), 1.72 (m, 2H, CyH), 1.47 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.49 (2C, C–OH), 155.08 (2C, C=N), 151.99 (2C, C–OMe), 119.42 (2C, C_{Ar}), 118.26 (2C, C_{Ar}), 117.47 (2C, C_{Ar}), 114.87 (2C, C_{Ar}), 72.76 (2C, C_{Cy}), 55.90 (2C, MeO), 33.04 (2C, C_{Cy}), 24.17 (2C, C_{Cy}).

3.11. N,N′-Bis(6-methoxysalicylidene)-(R,R′)-1,2-cyclohexanediamine ((R)L6H$_2$). Yellow solid product (91%), **ESI–MS** (m/z) 383.1 ($M + H^+$), $[\alpha]_D$ − 240 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2940 (*ν*, C–H), 2550 (*ν*, O–H), 1621 (*ν*, C=N), 1465 (*ν*, C=C), 1294 (*ν*, C–N), 1250, 1169 (*ν*, C–O), 864, 781 (*δ*, C–H), 725, 652. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 14.32 (s, 2H, 2OH), 8.68 (s, 2H, 2CH=N), 7.14 (t, *J* = 8.0, 2H, ArH), 6.46 (d, *J* = 8.5, 2H, ArH), 6.19 (d, *J* = 8.5, 2H, ArH), 3.71 (s, 6H, 2 MeO), 3.29 (m, 2H, CyH), 1.95 (m, 2H, CyH), 1.85 (m, 2H, CyH), 1.68 (m, 2H, CyH), 1.45 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.09 (2C, C–OH), 160.98 (2C, C=N), 159.71 (2C, C–OMe), 133.24 (2C, C_{Ar}), 110.15 (2C, C_{Ar}), 108.01 (2C, C_{Ar}), 99.59 (2C, C_{Ar}), 72.10 (2C, C_{Cy}), 55.52 (2C, MeO), 33.15 (2C, C_{Cy}), 24.20 (2C, C_{Cy}).

3.12. N,N′-Bis(6-methoxysalicylidene)-(S,S′)-1,2-cyclohexanediamine ((S)L6H$_2$). Yellow solid product (91%), **ESI–MS** (m/z) 383.0 ($M + H^+$), $[\alpha]_D$ + 239 (*c* 1.0; $CHCl_3$). **IR** (KBr, cm^{-1}): 2940 (*ν*, C–H), 2548 (*ν*, O–H), 1617 (*ν*, C=N), 1464 (*ν*, C=C), 1294 (*ν*, C–N), 1247, 1169 (*ν*, C–O), 864, 781 (*δ*, C–H), 725, 653. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 14.30 (s, 2H, 2OH), 8.68 (s, 2H, 2CH=N), 7.14 (t, *J* = 8.0, 2H, ArH), 6.46 (d, *J* = 8.0, 2H, ArH), 6.19 (d, *J* = 8.0, 2H, ArH), 3.71 (s, 6H, 2 MeO), 3.29 (m, 2H, CyH), 1.95 (m, 2H, CyH), 1.85 (m, 2H, CyH), 1.68 (m, 2H, CyH), 1.44 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 164.07 (2C, C–OH), 160.99 (2C, C=N), 159.72 (2C, C–OMe), 133.24 (2C, C_{Ar}), 110.15 (2C, C_{Ar}), 108.03 (2C, C_{Ar}), 99.61 (2C, C_{Ar}), 72.12 (2C, C_{Cy}), 55.53 (2C, MeO), 33.17 (2C, C_{Cy}), 24.21 (2C, C_{Cy}).

4. Preparation of Chiral Salen Platinum(II) Complexes

K_2PtCl_4 (212 mg, 0.5 mmol) was dissolved in 5 mL DMSO and then ligand L (0.5 mmol) dissolving in 5 mL DMSO was added. The reaction mixture was stirred at room

temperature for 0.5 h at pH 9.5. The reaction mixture was refluxed for 3 h, and then the mixture was cooled until room temperature. The yellow precipitate was filtered and washed by cool ethanol several times and dried *in vacuo*.

[Pt(*R*)(L1)]: yellow precipitate (72%), **ESI–MS** (m/z) 516.0 ($M + H^+$), $[\alpha]_D$ − 302 (*c* 0.1; DMSO). **IR** (KBr, cm^{-1}): 2925 (*ν*, C–H), 1600 (*ν*, C=N), 1448 (*ν*, C=C), 1317, 1190 (*ν*, C–N), 1150 (*ν*, C–O), 745 (*δ*, C–H), 567, 469. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 7.68 (s, 2H, 2CH=N), 7.41 (dt, *J* = 8.5; 1.5, 2H, ArH), 7.14 (d, *J* = 8.5, 2H, ArH), 7.03 (dd, *J* = 8.0, 2H, ArH), 6.53 (dt, *J* = 7.5; 1.0, 2H, ArH), 3.68 (m, 2H, CyH), 2.50 (m, 2H, CyH), 1.91 (m, 2H, CyH), 1.44 (m, 4H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 163.35 (2C, C–O), 150.71 (2C, C=N), 133.95 (2C, C_{Ar}), 133.56 (2C, C_{Ar}), 122.13 (4C, C_{Ar}), 115.70 (2C, C_{Ar}), 73.64 (2C, C_{Cy}), 27.69 (2C, C_{Cy}), 24.59 (2C, C_{Cy}).

[Pt(*S*)(L1)]: yellow precipitate (71%), **ESI–MS** (m/z) 516.0 ($M + H^+$), $[\alpha]_D$ + 299 (*c* 0.1; DMSO). **IR** (KBr, cm^{-1}): 2933 (*ν*, C–H), 1601 (*ν*, C=N), 1447 (*ν*, C=C), 1317, 1190 (*ν*, C–N), 1150 (*ν*, C–O), 749 (*δ*, C–H), 568, 471. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 7.66 (s, 2H, 2CH=N), 7.40 (dt, *J* = 8.5; 1.5, 2H, ArH), 7.13 (d, *J* = 8.5, 2H, ArH), 7.01 (dd, *J* = 8.0, 2H, ArH), 6.52 (dt, *J* = 7.5; 1.0, 2H, ArH), 3.68 (m, 2H, CyH), 2.49 (m, 2H, CyH), 1.90 (m, 2H, CyH), 1.43 (m, 4H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 163.39 (2C, C–O), 150.73 (2C, C=N), 133.91 (2C, C_{Ar}), 133.60 (2C, C_{Ar}), 122.15 (4C, C_{Ar}), 115.72 (2C, C_{Ar}), 73.65 (2C, C_{Cy}), 27.71 (2C, C_{Cy}), 24.60 (2C, C_{Cy}).

[Pt(*R*)(L2)]: yellow precipitate (72%), **ESI–MS** (m/z) 552.0 ($M + H^+$), $[\alpha]_D$ − 223 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2937 (*ν*, C–H), 1623 (*ν*, C=N), 1468 (*ν*, C=C), 1312, 1197 (*ν*, C–N), 1142 (*ν*, C–O), 814, 790 (*δ*, C–H), 571, 471. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): *δ* 8.43 (s, 2H, 2CH=N), 7.48 (dd, *J* = 9.5; 3.0, 2H, ArH), 7.33 (m, 2H, ArH), 6.88 (q, *J* = 5.0, 2H, ArH), 3.56 (m, 2H, CyH), 2.72 (m, 2H, CyH), 1.80 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.35 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): *δ* 159.28 (2C, C–O), 153.34 and 151.51 (2C, C–F), 151.30 (2C, C=N), 121.42 and 121.36 (2C, C_{Ar}), 121.15 and 120.95 (2C, C_{Ar}), 120.57 and 120.50 (2C, C_{Ar}), 116.69 and 116.51 (2C, C_{Ar}), 73.49 (2C, C_{Cy}), 27.13 (2C, C_{Cy}), 23.63 (2C, C_{Cy}).

[Pt(*S*)(L2)]: yellow precipitate (73%), **ESI–MS** (m/z) 551.9 ($M + H^+$), $[\alpha]_D$ + 221 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2938 (*ν*, C–H), 1622 (*ν*, C=N), 1464 (*ν*, C=C), 1311, 1198 (*ν*, C–N), 1141 (*ν*, C–O), 814, 789 (*δ*, C–H), 571, 470. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): *δ* 8.43 (s, 2H, 2CH=N), 7.48 (dd, *J* = 9.5; 3.5, 2H, ArH), 7.33 (m, 2H, ArH), 6.88 (q, *J* = 5.0, 2H, ArH), 3.56 (m, 2H, CyH), 2.72 (m, 2H, CyH), 1.80 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.35 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): *δ* 159.28 (2C, C–O), 153.36 and 151.53 (2C, C–F), 151.34 (2C, C=N), 121.44 and 121.38 (2C, C_{Ar}), 121.17 and 120.98 (2C, C_{Ar}), 120.59 and 120.52 (2C, C_{Ar}), 116.71 and 116.53 (2C, C_{Ar}), 73.51 (2C, C_{Cy}), 27.14 (2C, C_{Cy}), 23.64 (2C, C_{Cy}).

[Pt(*R*)(L3)]: yellow precipitate (67%), **ESI–MS** (m/z) 576.0 ($M + H^+$), $[\alpha]_D$ − 155 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2927 (*ν*, C–H), 1623 (*ν*, C=N), 1469 (*ν*, C=C), 1316, 1217 (*ν*, C–N), 1112 (*ν*, C–O), 1085, 854, 727 (*δ*, C–H), 564, 460. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): *δ* 8.36 (s, 2H, 2CH=N), 7.18 (dd, *J* = 8.5; 1.5, 2H, ArH), 7.03 (dd, *J* = 7.5; 1.5, 2H, ArH), 6.53 (t, *J* = 8.0, 2H, ArH), 3.77 (s, 6H, 2 MeO), 3.54 (m, 2H, CyH), 2.76 (m, 2H, CyH), 1.80 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.35 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): *δ* 154.20 (2C, C–O), 151.62 (2C, C=N), 150.95 (2C, C–OMe), 125.56 (2C, C_{Ar}), 121.70 (2C, C_{Ar}), 114.44 (2C, C_{Ar}), 113.75 (2C, C_{Ar}), 73.34 (2C, C_{Cy}), 55.41 (2C, 2 MeO), 27.08 (2C, C_{Cy}), 23.71 (2C, C_{Cy}).

[Pt(*S*)(L3)]: yellow precipitate (69%), **ESI–MS** (m/z) 576.0 ($M + H^+$), $[\alpha]_D$ + 157 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2928 (*ν*, C–H), 1616 (*ν*, C=N), 1468 (*ν*, C=C), 1316, 1213 (*ν*, C–N), 1115 (*ν*, C–O), 1083, 854, 727 (*δ*, C–H), 563, 459. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): *δ* 8.36 (s, 2H, 2CH=N), 7.18 (dd, *J* = 8.5; 1.5, 2H, ArH), 7.03 (dd, *J* = 7.5; 1.5, 2H, ArH), 6.53 (t, *J* = 8.0, 2H, ArH), 3.77 (s, 6H, 2 MeO), 3.54 (m, 2H, CyH), 2.76 (m, 2H, CyH), 1.80 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.35 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): *δ* 154.20 (2C, C–O), 151.64 (2C, C=N), 150.96 (2C, C–OMe), 125.56 (2C, C_{Ar}), 121.69 (2C, C_{Ar}), 114.44 (2C, C_{Ar}), 113.76 (2C, C_{Ar}), 73.35 (2C, C_{Cy}), 55.41 (2C, 2 MeO), 27.10 (2C, C_{Cy}), 23.72 (2C, C_{Cy}).

[Pt(*R*)(L4)]: yellow precipitate (71%), **ESI–MS** (m/z) 576.1 ($M + H^+$), $[\alpha]_D$ − 87 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2932 (*ν*, C–H), 1607 (*ν*, C=N), 1442 (*ν*, C=C), 1299, 1215 (*ν*, C–N), 1122 (*ν*, C–O), 832, 783 (*δ*, C–H), 548, 465. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 7.61 (s, 2H, 2CH=N), 6.98 (d, *J* = 8.5, 2H, ArH), 6.67 (d, *J* = 2.5, 2H, ArH), 6.20 (dd, *J* = 8.5; 2.5, 2H, ArH), 3.79 (s, 6H, 2 MeO), 3.58 (m, 2H, CyH), 2.45 (m, 2H, CyH), 1.85 (m, 2H, CyH), 1.39 (m, 4H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 165.60 (2C, C–O), 164.47 (2C, C–OMe), 149.71 (2C, C=N), 134.77 (2C, C_{Ar}), 116.38 (2C, C_{Ar}), 106.86 (2C, C_{Ar}), 103.40 (2C, C_{Ar}), 73.46 (2C, C_{Cy}), 55.28 (2C, 2 MeO), 27.70 (2C, C_{Cy}), 24.62 (2C, C_{Cy}).

[Pt(*S*)(L4)]: yellow precipitate (70%), **ESI–MS** (m/z) 576.0 ($M + H^+$), $[\alpha]_D$ + 89 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2935 (*ν*, C–H), 1601 (*ν*, C=N), 1439 (*ν*, C=C), 1299, 1215 (*ν*, C–N), 1120 (*ν*, C–O), 832, 778 (*δ*, C–H), 549, 463. **^{1}H–NMR** ($CDCl_3$, 500 MHz, ppm): *δ* 7.70 (s, 2H, 2CH=N), 7.05 (d, *J* = 8.5, 2H, ArH), 6.70 (d, *J* = 2.5, 2H, ArH), 6.23 (dd, *J* = 9.0; 2.5, 2H, ArH), 3.79 (s, 6H, 2 MeO), 3.55 (m, 2H, CyH), 2.52 (m, 2H, CyH), 1.89 (m, 2H, CyH), 1.46 (m, 2H, CyH), 1.38 (m, 2H, CyH). **^{13}C–NMR** ($CDCl_3$, 125 MHz, ppm): *δ* 165.72 (2C, C–O), 164.56 (2C, C–OMe), 149.76 (2C, C=N), 134.71 (2C, C_{Ar}), 116.33 (2C, C_{Ar}), 107.04 (2C, C_{Ar}), 103.48 (2C, C_{Ar}), 73.55 (2C, C_{Cy}), 55.30 (2C, 2 MeO), 27.78 (2C, C_{Cy}), 24.66 (2C, C_{Cy}).

[Pt(*R*)(L5)]: yellow precipitate (69%), **ESI–MS** (m/z) 576.0 ($M + H^+$), $[\alpha]_D$ − 186 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2934 (*ν*, C–H), 1626 (*ν*, C=N), 1476 (*ν*, C=C), 1291, 1221 (*ν*, C–N), 1160 (*ν*, C–O), 833, 788 (*δ*, C–H), 550, 452. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): *δ* 8.41 (s, 2H, 2CH=N), 7.18 (d, *J* = 3.5, 2H, ArH), 7.12 (dd, *J* = 9.0; 3.0, 2H, ArH), 6.82 (d, *J* = 9.0, 2H, ArH), 3.70 (s, 6H, 2 MeO), 3.53 (m, 2H, CyH), 2.75 (m, 2H, CyH), 1.81 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.36 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): *δ* 158.06 (2C, C–O), 151.26 (2C, C=N), 148.96 (2C, C–OMe), 123.03 (2C, C_{Ar}), 121.01 (2C, C_{Ar}), 120.42 (2C, C_{Ar}), 114.74 (2C, C_{Ar}), 73.40 (2C, C_{Cy}), 55.50 (2C, 2 MeO), 27.19 (2C, C_{Cy}), 23.72 (2C, C_{Cy}).

[Pt(*S*)(L5)]: yellow precipitate (71%), **ESI–MS** (m/z) 576.0 ($M + H^+$), $[\alpha]_D$ + 185 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2933 (ν, C–H), 1627 (ν, C=N), 1472 (ν, C=C), 1290, 1219 (ν, C–N), 1159 (ν, C–O), 833, 788 (δ, C–H), 550, 452. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): δ 8.41 (s, 2H, 2CH=N), 7.18 (d, J = 3.5, 2H, ArH), 7.12 (dd, J = 9.0; 3.0, 2H, ArH), 6.82 (d, J = 9.0, 2H, ArH), 3.70 (s, 6H, 2 MeO), 3.53 (m, 2H, CyH), 2.75 (m, 2H, CyH), 1.81 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.36 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): δ 158.06 (2C, C–O), 151.25 (2C, C=N), 148.96 (2C, C–OMe), 123.03 (2C, C_{Ar}), 121.01 (2C, C_{Ar}), 120.43 (2C, C_{Ar}), 114.74 (2C, C_{Ar}), 73.40 (2C, C_{Cy}), 55.50 (2C, 2 MeO), 27.18 (2C, C_{Cy}), 23.72 (2C, C_{Cy}).

[Pt(*R*)(L6)]: yellow precipitate (69%), **ESI–MS** (m/z) 575.9 ($M + H^+$), $[\alpha]_D$ − 143 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2937 (ν, C–H), 1602 (ν, C=N), 1456 (ν, C=C), 1314, 1249 (ν, C–N), 1201, 1105 (ν, C–O), 1033, 859, 786 (δ, C–H), 530, 450. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): δ 8.65 (s, 2H, 2CH=N), 7.28 (t, J = 8.5, 2H, ArH), 6.51 (d, J = 8.5, 2H, ArH), 6.18 (d, J = 7.5, 2H, ArH), 3.83 (s, 6H, 2 MeO), 3.54 (m, 2H, CyH), 2.63 (m, 2H, CyH), 1.83 (m, 2H, CyH), 1.52 (m, 2H, CyH), 1.37 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): δ 163.40 (2C, C–O), 159.42 (2C, C–OMe), 145.24 (2C, C=N), 132.38 (2C, C_{Ar}), 113.81 (2C, C_{Ar}), 112.14 (2C, C_{Ar}), 96.64 (2C, C_{Ar}), 73.64 (2C, C_{Cy}), 55.61 (2C, 2 MeO), 27.09 (2C, C_{Cy}), 23.66 (2C, C_{Cy}).

[Pt(*S*)(L6)]: yellow precipitate (68%), **ESI–MS** (m/z) 575.9 ($M + H^+$), $[\alpha]_D$ + 141 (*c* 0.03; DMSO). **IR** (KBr, cm^{-1}): 2938 (ν, C–H), 1602 (ν, C=N), 1456 (ν, C=C), 1314, 1248 (ν, C–N), 1201, 1103 (ν, C–O), 1033, 859, 786 (δ, C–H), 531, 450. **^{1}H–NMR** (DMSO-d^6, 500 MHz, ppm): δ 8.66 (s, 2H, 2CH=N), 7.29 (t, J = 8.5, 2H, ArH), 6.50 (d, J = 8.5, 2H, ArH), 6.20 (d, J = 7.5, 2H, ArH), 3.82 (s, 6H, 2 MeO), 3.53 (m, 2H, CyH), 2.63 (m, 2H, CyH), 1.81 (m, 2H, CyH), 1.51 (m, 2H, CyH), 1.34 (m, 2H, CyH). **^{13}C–NMR** (DMSO-d^6, 125 MHz, ppm): δ 163.42 (2C, C–O), 159.45 (2C, C–OMe), 145.30 (2C, C=N), 132.43 (2C, C_{Ar}), 113.83 (2C, C_{Ar}), 112.16 (2C, C_{Ar}), 96.69 (2C, C_{Ar}), 73.68 (2C, C_{Cy}), 55.65 (2C, 2 MeO), 27.12 (2C, C_{Cy}), 23.69 (2C, C_{Cy}).

5. Photophysical Property of Chiral Salen Platinum(II) Complexes

The UV-visible absorption spectra of the complexes were measured in DCM (dichloromethane) solutions (2×10^{-5} M) on Perkin Elmer Lambda UV-35 spectrophotometer. The emission spectra of the solutions were recorded on Horiba Fluorolog spectrofluorometer at room temperature. The obtained photophysical data are shown in Table 1.

6. *In Vitro* Cytotoxicity Assay

Human cancer cells KB and MCF-7 were cultured in DMEM with 10% fetal bovine serum, 100 μg/mL streptomycin, 100 units/mL penicillin, and 2 mmol/L L-glutamine at 37oC in humidified atmosphere with 5% CO_2 and 95% air. Cancer cells were cultivated in 96 well plates for 24 h followed by treating with different concentrations of complexes in DMSO for 24 h more. Then, testing cells were exposed to 10 μL of freshly prepared MTT (5 mM) solution and incubated for 2 h at 37oC in the atmosphere of 5% CO_2. The formazan crystals obtained during MTT incubation were dissolved in 100 μL of DMSO. The absorbance was recorded at 540 nm on Genios TECAN spectrophotometer. The experiments were carried out in triplicates for every concentration of the complexes. The percent viable cells were plotted as a function of concentration to determine the IC_{50} values presented in Table 2.

Table 1: Photophysical data of the chiral salen platinum(II) complexes.

Complex	λ_{abs} (ε)			λ_{em} (λ_{exc})
	$\pi - \pi^*$	$n - \pi^*$	MLCT	
1R	317 (10,215)	343 (12,045)	421 (4,635)	546 (421)
1S	317 (8,945)	343 (9,770)	421 (3,805)	542 (421)
2R	323 (11,870)	351 (12,305)	437 (5,270)	568 (437)
2S	323 (11.050)	351 (11,270)	437 (5,105)	566 (437)
3R	288 (13,235)	358 (14,375)	434 (4,100)	556 (434)
3S	288 (12,685)	358 (13,660)	434 (4,190)	552 (434)
4R	314 (23,800)	331 (25,250)	398 (10,080)	531 (398)
4S	314 (22,615)	332 (23,850)	398 (9,625)	529 (398)
5R	322 (14,230)	360 (11,520)	450 (6,260)	595 (450)
5S	322 (13,635)	360 (10,995)	450 (6,015)	593 (450)
6R	291 (14,485)	358 (28,020)	424 (4,965)	544 (423)
6S	291 (13,345)	358 (25,920)	423 (4,195)	540 (423)

7. Results and Discussion

7.1. Synthesis and Characterization. LH_2 ligands were formed by the condensation of (*R,R′*)-cyclohexanediamine and (*S,S′*)-cyclohexanediamine with salicylaldehydes (Figure 1), and then the precipitates formed were collected by filtration and washed by cold ethanol in high yields (>90%). All obtained chiral ligands (Table 3) were characterized by ESI-MS spectra, and the results obtained were in good agreement with those calculated for the suggested formulae. The IR spectra of the Schiff base ligands LH_2 revealed typical signals probably presented for new bonding of CH=N at 1617–1635 cm^{-1} and bonding of O–H at 2548–2665 cm^{-1}, C–N at 1248–1294 cm^{-1}, and Ar–O at 1163–1221 cm^{-1}. On the ^{1}H-NMR spectra, the singlet proton signals of CH=N performed the formation of these Schiff base ligands which were observed at δ = 8.09–8.68 ppm. The ^{1}H-NMR spectra exhibited proton signals at 1.44–3.32 ppm for CyHs, at 6.19–7.23 ppm for ArHs and at 12.80–14.30 ppm as singlet for OHs. The substituted methoxy groups showed characteristic signals at 3.70–3.86 ppm, and fluoro at 5-position of salicyl ring gave the proton signals of aromatic ring in mutiplet as usual. ^{13}C-NMR spectra exhibited the chemical shifts for carbons of CH=N at δ = 151.61–163.74 ppm. The typical signals for carbons of C–OH were at 163.71–164.90 ppm. The signals at 99.61–133.24 ppm could belong to carbon signals of the salicylidene moiety without substitution. The chemical shifts for carbons with substituted groups moved the higher field compared to the carbon signals without substituted groups, carbons of C–OMe at

Table 2: The cytotoxicity of chiral Pt(II) complexes *in vitro*.

Complex	IC_{50} (μM)	
	KB	MCF-7
1R	12.29	10.08
1S	11.26	7.15
2R	29.04	27.80
2S	22.43	8.97
3R	22.26	9,27
3S	21.22	8.12
4R	30.71	29.01
4S	13.32	10.01
5R	13.91	15.58
5S	10.71	7.51
6R	10.92	7.18
6S	10.61	5.72
Ellipticine	1.22	2.07

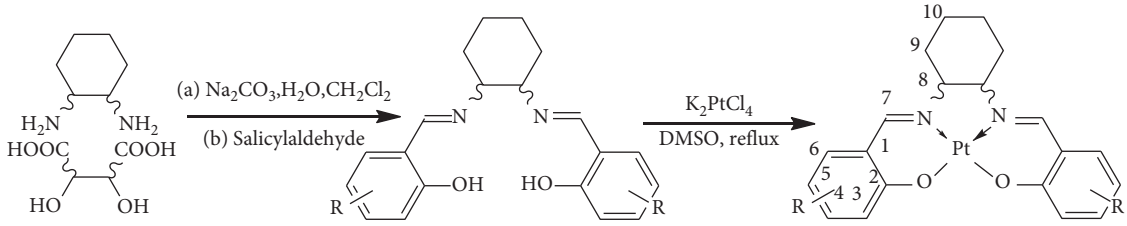

Figure 1: Synthesis of chiral salen ligands and Pt(II) complexes.

Table 3: Chiral salen ligands and their Pt(II) complexes.

R	Ligand	Complex
H	(*R*)L1H_2	[Pt(*R*)(L1)] (**1R**)
H	(*S*)L1H_2	[Pt(*S*)(L1)] (**1S**)
5-F	(*R*)L2H_2	[Pt(*R*)(L2)] (**2R**)
5-F	(*S*)L2H_2	[Pt(*S*)(L2)] (**2S**)
3-OMe	(*R*)L3H_2	[Pt(*R*)(L3)] (**3R**)
3-OMe	(*S*)L3H_2	[Pt(*S*)(L3)] (**3S**)
4-OMe	(*R*)L4H_2	[Pt(*R*)(L4)] (**4R**)
4-OMe	(*S*)L4H_2	[Pt(*S*)(L4)] (**4S**)
5-OMe	(*R*)L5H_2	[Pt(*R*)(L5)] (**5R**)
5-OMe	(*S*)L5H_2	[Pt(*S*)(L5)] (**5S**)
6-OMe	(*R*)L6H_2	[Pt(*R*)(L6)] (**6R**)
6-OMe	(*S*)L6H_2	[Pt(*S*)(L6)] (**6S**)

148.26–163.45 ppm. The chemical shifts for aromatic carbons of salicylidene moiety with fluoro at 5-position exhibited double signals. The chemical shifts for cyclohexane ring carbons were at 24.05–72.76 ppm, and for MeO groups, they were about 55.29–56.04 ppm.

Pt(II) complexes in the list (Table 3) were obtained in moderate yields (67–73%) by the reaction of K_2PtCl_4 with each ligand in DMSO. The complexes were characterized by ESI-MS, IR, and NMR. The results received by ESI-MS were suitable to the suggested formulae (Figure 1). The IR spectra of obtained complexes showed the typical signals at 1601–1627 cm^{-1} for C=N, 1190–1248 for C–N, and 1103–1159 cm^{-1} for Ar–O bonding stretching vibrations. There was no signal for O–H bonding in the complexes, and there were signals for Pt–N and Pt–O of new bonding stretching vibrations at 531–571 $cm^{-1}$and 450–472 cm^{-1}, respectively, conforming that the Pt(II) complexes were coordinated. The ^{1}H-NMR spectra revealed the proton signals of CH=N at $\delta = 7.62$–8.66 ppm, ArHs at 6.10–7.48 ppm, and CyHs at 1.33–3.70 ppm. The substituted methoxy groups showed characteristic signals at 3.70–3.82 ppm and aromatic proton signals with fluoro at 5-position salicyl ring were shown in mutiplet. ^{13}C-NMR spectra exhibited the typical signals at 154.20–164.65 ppm for carbons of C–O and 145.30–151.64 ppm for carbons of CH=N. The carbon signals of salicylidene moiety could be at 96.69–134.94 ppm, and for cyclohexane ring, they were at 23.63–73.71 ppm. The aromatic carbon signals linking the substituted groups must be exhibited at 153.36 and 151.51 ppm for C–F and 148.96–163.74 ppm for C–OMe. The carbon signals of the substituted methoxy groups could be shown at 54.59–55.65 ppm.

It was similar to IR spectra, and there were no big different signals on ^{1}H and ^{13}C-NMR spectra of (*R*)- and (*S*)-enantiomers of ligands and platinum(II) complexes except opposite rotations of polarized light. The CD spectra of these couples of enantiomeric Pt(II) complexes in methanol or DCM (4*R*, 4*S* and 6*R*, 6*S*) were measured at room temperature from 235 to 400 nm. The couples of chiral enantiomers emitted the equal intense peaks with the opposite orientation (Figure 2), respectively, which demonstrated the existence of the chiral enantiomers.

7.2. Photophysical Property of Chiral Salen Platinum(II) Complexes. The photophysical data are shown in Table 1. When dissolved in DCM, all complexes afforded the yellow

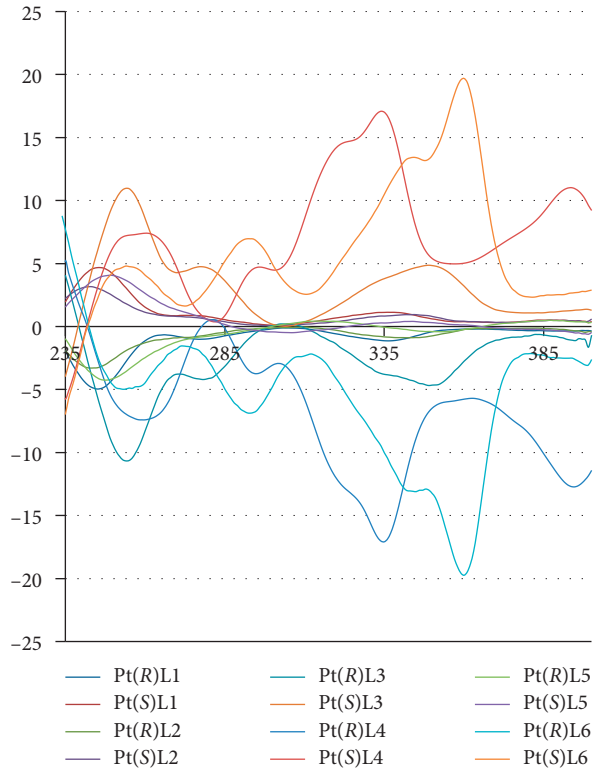

Figure 2: CD spectra of chiral salen Pt(II) complexes.

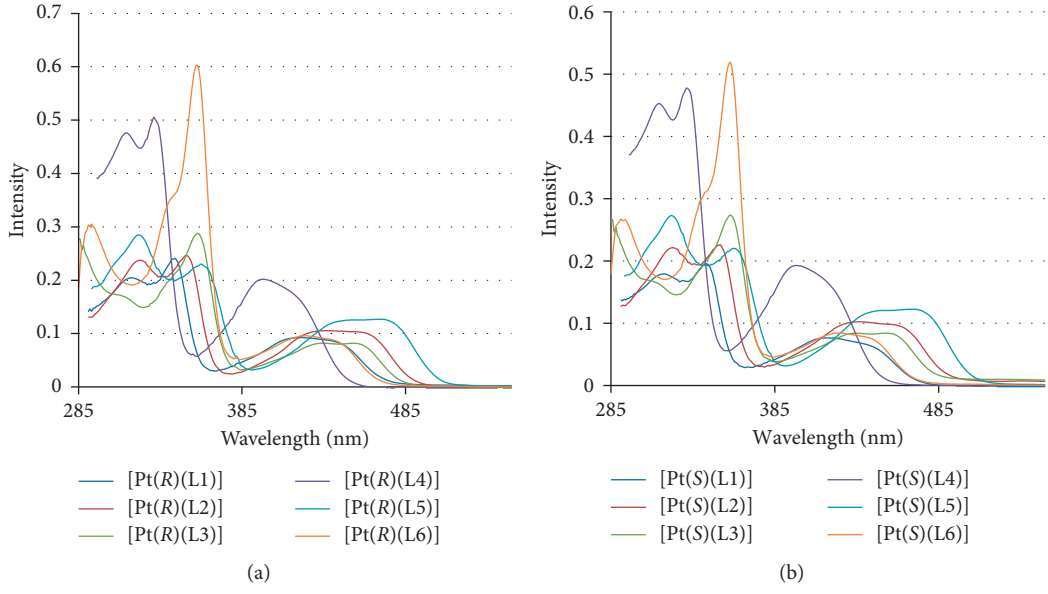

Figure 3: UV-visible spectra of chiral salen Pt(II) complexes.

solution and exhibited UV-Vis absorption and emission spectra.

There were three main absorption bands as usual on UV-Vis spectra, two intense absorption bands at 288–323 nm and 331–360 nm are probably attributed to intraligand absorption, and the visible band at 398–450 nm may belong to the MLCT (metal-to-ligand charge transfer) state due to Pt(5d) $\longrightarrow \pi^*$ transition (Figure 3). There were no meaningful difference in $\lambda_{max(abs)}$ between enantiomeric Pt(II) complexes in (*R*) and (*S*) configuration. The luminescence spectra from the corresponding excited state possessed an emission maximum at 529–595 nm. The emission maximum wavelengths of complexes' (*S*)-enantiomers were similar to (*R*)-enantiomers (Table 1). The Pt(II) complexes with substituted groups at aromatic ring C5-position show emission peaks at 566–595 nm, red-shifted

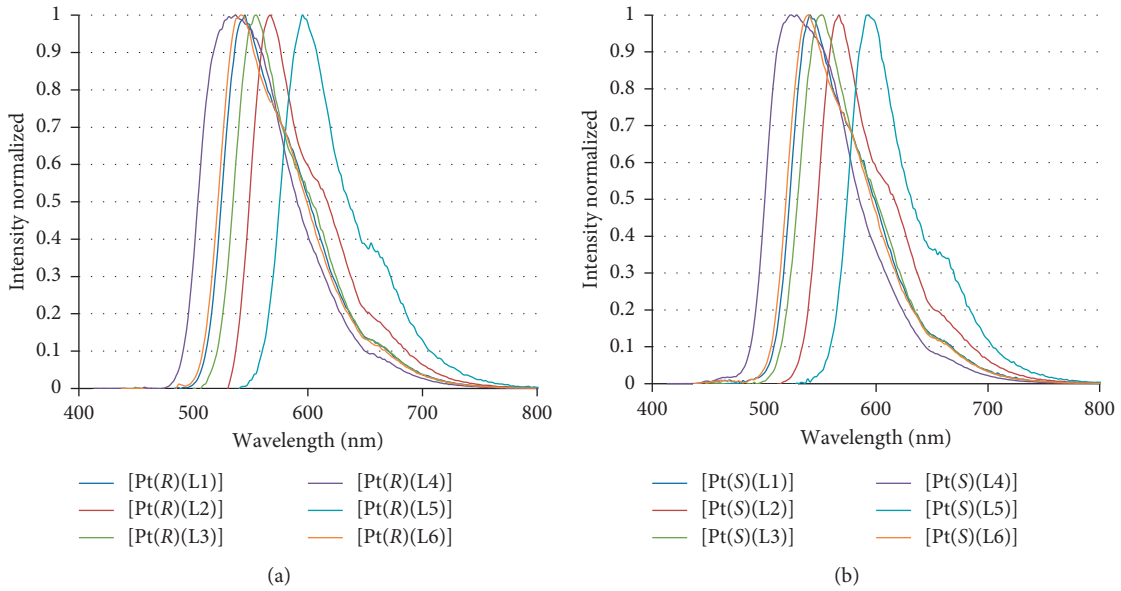

Figure 4: Emission spectra of chiral salen Pt(II) complexes.

from ca. 542 nm. The complexes with MeO groups at different positions exhibited different emission wavelengths; the substituted group which occurred at C4 and C6 position of salicylidene moiety of the complexes shifted emission peaks to blue range while the group at C3 and C5 position shifted those to red region (Figure 4). MeO groups at C3 and C5 had *ortho*- and *para*-effect to the bond C–O, so they may make the band gap HOMO-LUMO of the bond O–Pt to be narrower. MeO groups at C4 and C6 had *meta*-effect to the bond C–O, so they may make the band gap HOMO-LUMO of the bond O–Pt to be bigger.

7.3. In Vitro Cytotoxicity Assay. In order to estimate possible effect of ligand enantiomers and substituted groups to the platinum(II) complexes' antitumor activity, the *in vitro* cytotoxicity of the studied Pt(II) complexes was validated against two human cancer cell lines of KB and MCF-7. The cytotoxicity of ellipticine, a standard anticancer compound, was also evaluated in the same condition for comparison. The IC_{50} values (the concentration that inhibited in 50% cellular proliferation) of the obtained complexes are presented in Table 2.

It was noted that all complexes exhibited the antitumor effect with low IC_{50} value (<50 μM) for KB and MCF-7 human cancer cell lines. In particular, complexes **1S**, **5S**, **6R,** and **6S** had good anticancer activity for both KB and MCF-7 human cancer cell lines. Enantiomers in (*S*) configuration gave more effect for the Pt(II) complexes' cytotoxicity than ones in (*R*) configuration (Table 2). The obtained results were similar to the previous results of chiral Ru(II) and Mn(III) salen complexes because the DNA binding affinity of chiral salen complexes (*S*)- would be greater than (*R*)- [25, 26]. The complexes **3**–**6** with different methoxy group positions on salicyl ring had different activities. The introduction of methoxy groups to salicylidene moiety afforded the complex **6S** with the best antitumor activity obviously for KB and MCF-7 human cancer cells. The complex **6S** had the anticancer activity for MCF-7 human cancer cells with IC_{50} of 5.72 μM which was quite close to IC_{50} of the standard compound ellipticine (2.07 μM).

8. Conclusions

In this research, a series of platinum(II) complexes with chiral tetradentate salen ligands were synthesized from salicylaldehydes and (*R*,*R*′)-cyclohenxanediamine and (*S*,*S*′)-cyclohenxanediamine and characterized by IR, ESI-MS, NMR, and CD spectra. Photophysical properties showed their typical absorption and luminescence in UV-visible region. The luminescent spectra exhibited the effect of substituted groups to their luminescent wavelengths obviously; however, there was no big difference between enantiomeric complexes in (*R*) and (*S*) configuration. Complex **5** with the substituted MeO at C5-position of salicylidene moiety gave farthest red-shift luminescence (at 595 nm). The *in vitro* antitumor activity of the studied complexes have been evaluated against KB and MCF-7 human cancer cells by MTT assay, and the results showed all complexes had activity against tested human cancer cell lines. The antitumor activity of enantiomers in (*S*) configuration was more favourable than enantiomers in (*R*) configuration. The complexes **6S** were the most effective agents to KB and MCF-7 human cancer cells, respectively.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

This section includes the spectral data of synthetic chiral ligands and Pt(II) complexes. These data include ESI-MS, IR, ^{1}H-NMR, and ^{13}H-NMR spectra of the synthesized chiral ligands (*R*)L1H_2 and (*S*)L1H_2, (*R*)L2H_2 and (*S*)L2H_2, (*R*)L3H_2 and (*S*)L3H_2, (*R*)L4H_2 and (*S*)L4H_2, (*R*)L5H_2 and (*S*)L5H_2, and (*R*)L6H_2 and (*S*)L6H_2. The ESI-MS, IR, ^{1}H-NMR, ^{13}C-NMR, and CD spectra of obtained Pt(II) complexes [Pt(*R*)(L1)] and [Pt(*S*)(L1)], [Pt(*R*)(L2)] and [Pt(*S*)(L2)], [Pt(*R*)(L3)] and [Pt(*S*)(L3)], [Pt(*R*)(L4)] and [Pt(*S*)(L4)], [Pt(*R*)(L5)] and [Pt(*S*)(L5)], and [Pt(*R*)(L6)] and [Pt(*S*)(L6)] are also provided. (*Supplementary Materials*)

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