Inorganic Chemistry Communications 21 (2012) 35–38

Contents lists available at SciVerse ScienceDirect

Inorganic Chemistry Communications

journal homepage: www.elsevier.com/locate/inoche

Fac-tricarbonyl(pentylcarbonato)(α-diimine)rhenium complexes: One-pot synthesis, characterization, fluorescence studies, and cytotoxic activity against human MDA-MB-231 breast, CCl-227 colon and BxPC-3 pancreatic carcinoma cell lines

Michael K. Mbagu [a], Divine N. Kebulu [a], Angela Winstead [a], Saroj K. Pramanik [b], Hirendra N. Banerjee [c], Maurice O. Iwunze [a], James M. Wachira [b], George E. Greco [d], Gregory K. Haynes [a], Amanda Sehmer [e], Fazlul H. Sarkar [f], Douglas M. Ho [g], Robert D. Pike [h], Santosh K. Mandal [a,*]

[a] Department of Chemistry, Morgan State University, Baltimore, MD 21251, USA
[b] Department of Biology, Morgan State University, Baltimore, MD 21251, USA
[c] Department of Biology, Elizabeth City State University, Elizabeth City, NC 27909, USA
[d] Department of Chemistry, Goucher College, Baltimore, MD 21204, USA
[e] Karmanos Cancer Institute, Detroit, MI 48201, USA
[f] Department of Pathology, Wayne State University School of Medicine, Detroit, MI 48201, USA
[g] Department of Chemistry, Princeton University, Princeton, NJ 08544, USA
[h] Department of Chemistry, College of William and Mary, Williamsburg, VA 23167, USA

ARTICLE INFO

Article history:
Received 17 January 2012
Accepted 15 April 2012
Available online 23 April 2012

Keywords:
Fac-tricarbonyl(pentylcarbonato)(α-diimine) rhenium complexes
X-ray
Fluorescence
BxPC-3 pancreatic cancer cell lines
CCL-227 colon cancer cell lines
MDA-MB-231 breast cancer cell lines

ABSTRACT

A series of pentylcarbonato complexes of the general formula *fac*-$(CO)_3$(α-diimine)ReOC(O)O$(CH_2)_4CH_3$ (**1**–**7**) was synthesized from the reactions of $Re_2(CO)_{10}$ with the corresponding α-diimines in refluxed 1-pentanol while CO_2 was bubbled through the solutions. The α-diimines in **1**–**7** are 2,2′-bipyridyl, 1,10-phenanthroline, 5-methyl-1,10-phenanthroline, neocuproin, 5,6-dimethyl-1,10-phenanthroline, bathophenanthroline, and bathocuproin, respectively. Complexes **1**–**7** have been characterized spectroscopically and by elemental analyses. Additionally, **1** and **6** have been characterized in the solid state by X-ray crystallography. The electronic absorption spectra of **1**–**7** exhibit metal-to-ligand charge-transfer (MLCT) absorption maxima in the range 343–371 nm in acetonitrile. The emission maxima range from 513 to 532 nm. The average life-time and quantum yield are 1.074 ns and 0.011 respectively. Cytotoxicity studies using a few of these pentylcarbonato complexes reveal that the complexes are cytotoxic against BxPC-3 pancreatic, CCL-227 colon, and MDA-MB-231 breast cancer cell lines.

Transition metal alkylcarbonato complexes have found applications in the conversion of methanol to dimethylcarbonate [1], synthesis of dialkylcarbonates [2], and as the starting materials for the synthesis of important organometallic complexes including perrhenato and amino acid complexes [3]. A general method of synthesis of alkylcarbonato complexes is to insert CO_2 into the metal-alkoxide bond (M-OR) of an alkoxo complex which is synthesized from the metathesis reaction of a halo, triflato, or tosylato complex with an alkali metal alkoxide [4]. Although the chemistry of metal alkoxo complexes has been explored in great detail, the chemistry including the photophysical properties and biological applications of metal alkylcarbonato complexes is almost unknown. Here, we report the one-pot synthesis of seven pentylcarbonato complexes, *fac*-$(CO)_3$(α-diimine)ReOC(O)OC_5H_{11} (**1**–**7**), the X-ray structures of **1** and **6**, and the fluorescence and cytotoxic properties of **1**–**7**. The α-diimines in **1**–**7** are 2,2′-bipyridyl, 1,10-phenanthroline, 5-methyl-1,10-phenanthroline, neocuproin, 5,6-dimethyl-1,10-phenanthroline, bathophenanthroline, and bathocuproin, respectively.

The reactions of $Re_2(CO)_{10}$ and α-diimines in 1-pentanol in the presence of CO_2 afforded the corresponding pentylcarbonato complexes (**1**–**7**) in moderate to high yields according to Eq. (1) [5]:

$$Re_2(CO)_{10} + 2\,(\alpha\text{−diimine}) + 2C_5H_{11}OH + 2CO_2 \rightarrow 2\,(CO)_3(\alpha\text{−diimine})ReOC(O)OC_5H_{11}(\mathbf{1}\text{–}\mathbf{7}) + 4CO + H_2 \quad (1)$$

* Corresponding author. Tel.: +1 443 885 1665; fax: +1 443 885 8286.
E-mail addresses: mmbagu@gmail.com (MK.. Mbagu), kndode@yahoo.com (DN.. Kebulu), angela.winstead@morgan.edu (A. Winstead), sarojpramanik@yahoo.ca (SK.. Pramanik), bhirendranath@mail.ecsu.edu (HN.. Banerjee), maurice.iwunze@morgan.edu (MO.. Iwunze), james.wachira@morgan.edu (JM.. Wachira), ggreco@goucher.edu (GE.. Greco), gregory.haynes@morgan.edu (GK.. Haynes), sehmera@karmanos.org (A. Sehmer), fsarkar@med.wayne.edu (FH.. Sarkar), doug32009@gmail.com (DM.. Ho), rdpike@wm.edu (RD.. Pike), santosh.mandal@gmail.com (SK.. Mandal).

1387-7003/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.inoche.2012.04.004

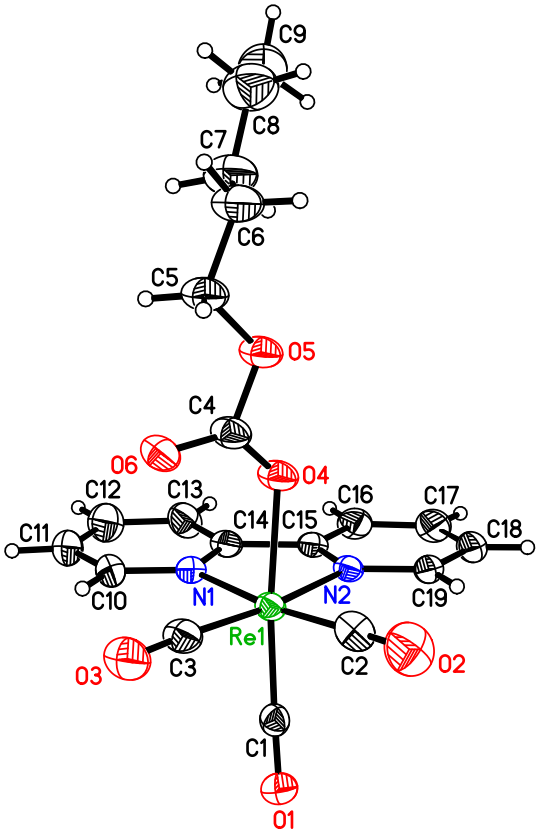

Fig. 1. The X-ray structure of **1**. Selected bond lengths and angles (Å, °): Re1–C1 1.898(4), Re1–C2 1.921(5), Re1–C3 1.924(4), Re1–N1 2.178(3), Re1–N2 2.164(3), Re1–O4 2.142(3), C1–O1 1.155(4), C2–O2 1.146(5), C3–O3 1.149(5), C4–O4 1.259(4), C4–O5 1.358(4), C4–O6 1.223(4), C1–Re1–O4 173.9(3), C2–Re1–O4 90.7(4), C3–Re1–O4 98.0(3), N1–Re1–O4 84.9(4), N2–Re1–O4 80.2(3), N1–Re1–N2 74.87(12).

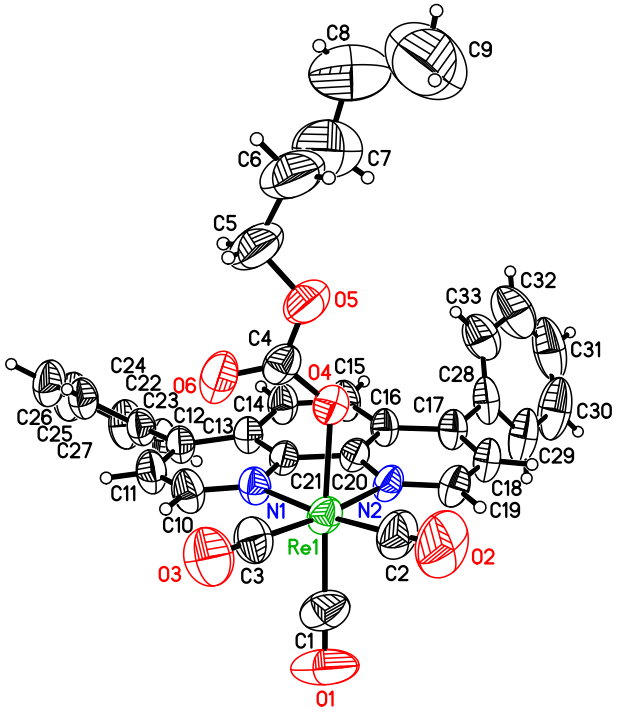

Fig. 2. The X-ray structure of **6**. Selected bond lengths and angles (Å, °): Re1–C1 1.911(7), Re1–C2 1.927(6), Re1–C3 1.934(6), Re1–N1 2.187(4), Re1–N2 2.195(4), Re1–O4 2.157(3), C1–O1 1.157(8), C2–O2 1.141(8), C3–O3 1.141(7), C4–O4 1.274(7), C4–O5 1.349(8), C4–O6 1.225(8), C1–Re1–O4 175.0(2), C2–Re1–O4 90.9(2), C3–Re1–O4 98.5(2), N1–Re1–O4 84.54(16), N2–Re1–O4 79.77(15), N1–Re1–N2 75.40(14).

Table 1
Photophysical parameters of **1**–**7** in acetonitrile.

Complex	λ_{max}[a]	ε[b] × 10^{-3}	λ_{Ex}[c]	λ_{Em}[d]	Φ[e]	τ_o[f]
1	364	1.549	327	532	0.023	2.359
2	364	1.489	372	530	0.009	1.151
3	367.	1.254	376	529	0.011	1.60
4	357	1.529	386	527	0.011	1.031
5	371	1.199	384	530	0.004	0.560
6	343	3.682	371	529	0.019	0.802
7	363	4.834	448	513	0.002	0.015

[a] Maximum wavelength, nm.
[b] Molar absorptivity, M^{-1} cm^{-1}.
[c] Excitation wavelength, nm.
[d] Emission wavelength, nm.
[e] Quantum yield.
[f] Life-time, ns.

The reaction mechanism for the formation of **1**–**7** was not explored, but one plausible scheme is that a $[Re(CO)_3(\alpha\text{-diimine})]_2$ dimer is initially formed which reacts with 1-pentanol to yield the corresponding $(CO)_3(\alpha\text{-diimine})ReOC_5H_{11}$ pentyloxo complex which then undergoes CO_2 insertion into the Re–O bond to ultimately produce *fac*-$(CO)_3(\alpha\text{-diimine})ReOC(O)OC_5H_{11}$. Due to the *fac* geometry, the IR spectrum of each exhibits three strong $\nu(C{\equiv}O)$'s. Additionally, one medium intensity $\nu(C{=}O)$ is observed due to the $-OC(=O)OC_5H_{11}$ ligand. The ^1H NMR spectrum of each shows the characteristic resonances due to the aliphatic protons of the C_5H_{11} group. The ^{13}C NMR spectrum of each exhibits the two characteristic low-field resonances with an intensity ratio of 2:1 due to three terminal C≡O's, a low-field resonance due to the C=O of the pentylcarbonato ligand and characteristic resonances due to the aromatic and aliphatic carbons. The molecular structures of **1** and **6** were established by X-ray crystallography [6] and are shown in Figs. 1 and 2, respectively. The Re atoms possess distorted octahedral coordination geometries consisting of three carbonyls arranged in a facial fashion, a chelated α-diimine, and a monodentate pentylcarbonato ligand. The axial Re – CO bond is slightly shorter than the equatorial Re – CO bonds consistent with the pentylcarbonato ligand having a slightly weaker trans-influence than the α-diimine ligand. The slight lengthening in the C1 – O1 bonds are also consistent with the slight shortening in the axial Re – CO bonds. While small amounts of trans CO/Cl disorder have been previously observed in related complexes [7], there is no evidence of any comparable trans $CO/OC(O)OC_5H_{11}$ disorder in **1** or **6**.

Although the UV–vis spectrum of any alkylcarbonato complex has not been reported to-date, the UV–vis spectra of **1**–**7** are very similar to those of analogous *fac*-tricarbonyl (α-diimine)rhenium(I) complexes [8]. The higher energy absorptions are due to the expected diimine ligand-centered π–π* transitions and the lowest energy absorptions are due to metal-to-ligand charge-transfer (MLCT) transitions. Complexes **1**–**7** are luminescent in both solid-states and solutions. The emissions

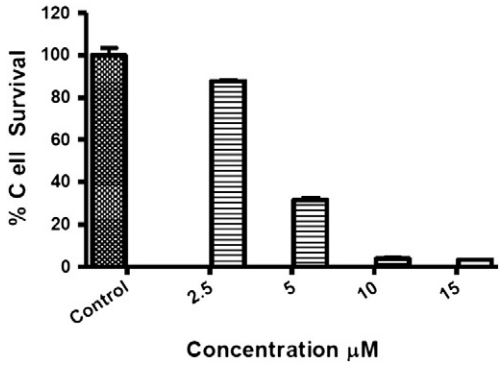

Fig. 3. Pancreatic cancer cell lines, BxPC-3 exposed to various concentrations of **4** in DMSO. Control represents cells exposed to DMSO only.

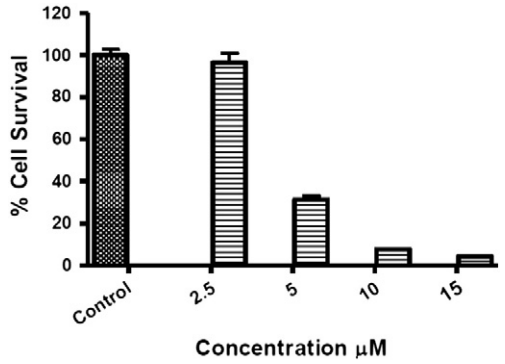

Fig. 4. Pancreatic cancer cell lines, BxPC-3 exposed to various concentrations of **6** in DMSO for 72 h. Control represents cells exposed to DMSO only.

are assigned predominantly to the excited states of ^{3}MLCT ($d\pi(Re) \rightarrow \pi^*$ (diimine)). The quantum yields and fluorescence life-times were determined according to published procedures [8]. The photophysical parameters of **1**–**7** in acetonitrile solutions are summarized in Table 1 (the higher energy ligand peaks are not included).

Cytotoxicity studies in DMSO [9] reveal that **4** and **6** are active against BxPC-3 pancreatic cancer cell lines with IC_{50} being approximately 4 μM (see Figs. 3 and 4). Additional studies with 4 μM **1**–**7** indicate that **1**–**4**, **6** and **7** are active against CCL-227 colon and MDA-MB-231 breast cancer cell lines. Interestingly, **6** and **7** are highly effective against CCL-227 colon cancer cell lines and **1** is very effective against estrogen receptor-negative MDA-MB-231 breast cancer cell lines (Fig.5). The mechanism of action involved is currently unknown, but presumably does not involve DNA-binding based on a gel electrophoresis experiment involving the incubation of **4** with DNA [10] and UV–vis spectra of a solution of **4** and DNA in DMSO and phosphate buffer [10,11]. Detailed cytotoxicity studies employing a broader range of concentrations for **1**–**7** are in progress, as well as further studies to ascertain the mechanism of action of these *fac*-tricarbonyl(α-diimine)rhenium(I) complexes.

The pentylcarbonato complexes (**1**–**7**) are stable in ordinary organic solvents in the presence of CO_2. However, they undergo deinsertion of CO_2 (< 5%) to produce the corresponding pentyloxo complexes, *fac*-$(CO)_3$(α-diimine)$ReOC_5H_{11}$ in the absence of CO_2. When any of those complexes (**1**–**7**) is dissolved in the cell culture medium and left undisturbed for 72 h, the IR spectrum of the CH_2Cl_2-extract confirms the presence of the pentylcarbonato complex (**1**–**7**) and the corresponding pentyloxo complex, *fac*-$(CO)_3$(α-diimine)$ReOC_5H_{11}$.

Acknowledgment

This research was supported in part by an appointment to the US Nuclear Regulatory Commission's HBCU Faculty Research Participation Program administered by the Oak Ridge Institute for Science and Education. This project was also partially supported by Grant number G11HD038439 from the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health.

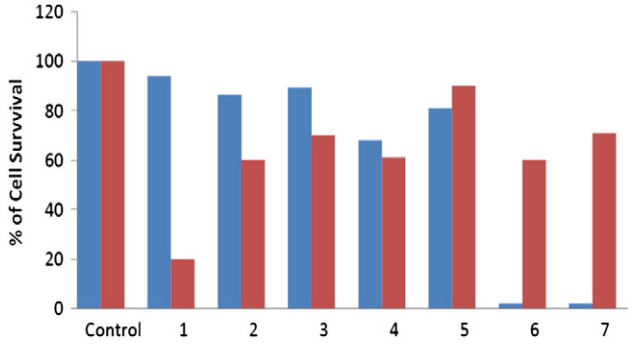

Fig. 5. Colon cancer cell lines CCL-227 (blue) and breast cancer cell lines MDA-MB-231 (red) were exposed to 4 μM DMSO solutions of **1**–**7** for 72 h.

Appendix A. Supplementary material

CCDC 749606 and CCDC 749607 contain the supplementary crystallographic data for **1** and **6**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Supplementary data to this article can be found online at doi:10.1016/j.inoche.2012.04.004.

References

[1] C.A. Stewart, D.A. Dickie, R.A. Kemp, SANDIA REPORT: SAND2009-7228, 2009, pp. 1–64, and the references cited therein.
[2] M. Kato, T. Ito, Inorg. Chem. 24 (1985) 504–508.
[3] (a) D.A. Brown, D.M. Kimari, A.M. Duzs-Moore, T.A. Budzichowski, D.M. Ho, S.K. Mandal, J. Organomet. Chem. 658 (2002) 88–93;
(b) D.K. Orsa, M.O. Iwunze, S.K. Pramanik, G.E. Greco, S.K. Mandal, 238th ACS National Meeting, Washington, D.C. August 16–20, 2009, INOR 311.
[4] S.K. Mandal, D.M. Ho, M. Orchin, Organometallics 12 (1993) 1714–1719.
[5] Synthesis of **1**–**7**: In a typical experiment a mixture of about 1.5 mmol of $Re_2(CO)_{10}$ and 3.0 mmol of an α-diimine was refluxed in 50 mL of 1-pentanol for 24–36 h while CO_2 was bubbled through the solution. The mixture was cooled to −5 °C. Microcrystals of **1**–**7** were collected through filtration. Data for **1**: Yield, 83%. MP 198–201 °C. Anal. Calcd. for $C_{19}H_{19}N_2O_6Re$. 0.25 CH_2Cl_2: C, 39.95%; H, 3.39%; N, 4.84%. Found: C, 40.18%; H, 3.20%; N, 4.97%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2024s, 1920s, 1896s; ν(C═O) 1661 m, br. ^{1}H NMR ($CDCl_3$, δ): 9.11 (s, br, 2H, Bipy), 8.16 (s, br, 2H, Bipy), 8.00 (s, br, 2H, Bipy), 7.50 (s, br, 2H, Bipy), 3.78 (s, br, 2H, OCH_2), 1.73–1.21 (m, 6H, $CH_2CH_2CH_2$), 0.81 (s, br, 3H, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.5 (2C≡O), 193.3 (C≡O), 159.1 (C≡O), 155.8 (Bipy), 153.8 (Bipy), 139.1 (Bipy), 126.9 (Bipy), 122.9 (Bipy), 66.4 (−OCH_2), 28.8 (−OCH_2CH_2), 28.0 ($CH_2CH_2CH_3$), 22.4 (CH_2CH_3), 14.0 (CH_3). Data for **2**: Yield, 66%. MP 218–20 °C. Anal. Calcd. for $C_{21}H_{19}N_2O_6Re$. 0.15 CH_2Cl_2: C, 42.74%; H, 3.27%; N, 4.71%. Found: C, 42.87%; H, 2.94%; N, 4.81%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2024s, 1920s, 1896s; ν(C═O) 1660 m, br. ^{1}H NMR ($CDCl_3$, δ): 9.50 (s, br, 2H, Phen), 8.53 (s, br, 2H, Phen), 7.99 (s, br, 2H, Phen), 7.84 (s, br, 2H, Phen), 3.73 (s, br, 2H, −OCH_2), 1.62–1.16(m, 6H, $CH_2CH_2CH_2$), 0.79 (s, br, 3H, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.5 (2C≡O), 193.5 (C≡O), 159.2 (C═O), 153.9 (Phen), 147.2 (Phen), 138.2 (Phen), 130.6 (Phen), 127.5 (Phen), 125.7 (Phen), 66.4 (−OCH_2), 28.8 (−OCH_2CH_2), 28.0 ($CH_2CH_2CH_3$), 22.4 (CH_2CH_3), 14.0 (CH_3). Data for **3**: Yield, 81%. MP 180–84 °C. Anal. Calcd. for $C_{22}H_{21}N_2O_6Re$: C, 44.36%; H, 3.55%; N, 4.70%. Found: C, 44.45; H, 3.32%; N, 4.71%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2023s, 1919s, 1895s; ν(C═O) 1661 m, br. ^{1}H NMR ($CDCl_3$, δ): 9.37 (dd, 1H, J = 5.1, 1.3 Hz), 9.37 (dd, 1H, J = 5.1, 1.3 Hz), 8.66 (dd, 1H, J = 8.5, 1.3 Hz), 8.44 (dd, 1H, J = 8.2 Hz, 1.3 Hz), 7.87 (dd, 1H, J = 8.4, 5.1 Hz), 7.80 (s, 1H), 7.79 (dd, 1H, J = 8.2, 5.1 Hz), 3.72 (t, 2H, J = 7.1 Hz, −OCH_2), 2.84 (d, 3H, J = 0.7 Hz, H_3C-Phen), 1.42 (quint, 2H, J = 7.2 Hz, -OCH_2CH_2), 1.22–1.11 (m, 4H, −$CH_2CH_2CH_3$), 0.80 (t, 3 H, J = 5.5 Hz, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.6 (2C≡O), 193.4 (C≡O), 159.2 (C═O), 153.4 (Phen), 152.9 (Phen), 147.4 (Phen), 146.5 (Phen), 137.5 (Phen), 135.3 (Phen), 135.2 (Phen), 130.9 (Phen), 130.3 (Phen), 126.4 (Phen), 125.7 (Phen), 125.5 (Phen), 66.4 (−OCH_2), 28.8 (−OCH_2CH_2), 28.0 ($CH_2CH_2CH_3$), 22.4 (CH_2CH_3), 18.8 (H_3C-Phen), 14.0 (CH_3). Data for **4**: Yield, 76%. MP 175–78 °C. Anal. Calcd. for $C_{23}H_{23}N_2O_6Re$: C, 45.31%; H, 3.80%; N, 4.59%. Found: C, 45.07%; H, 3.56%; N, 4.62%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2023s, 1916s, 1894s; ν(C═O) 1661 m, br. ^{1}H NMR ($CDCl_3$, δ): 8.29 (d, 2H, J = 8.3 Hz), 7.80 (s, 1H), 7.68 (d, 2H, J = 8.3 Hz), 3.59 (t, 2H, J = 6.9 Hz, −OCH_2), 3.34 (s, 3H, H_3C-Phen), 1.29 (quint, 2H, J = 7.2 Hz, −OCH_2CH_2), 1.14 (m, 2 H, −$CH_2CH_2CH_3$), 1.03 (m, 2 H, −CH_2CH_3), 0.77 (t, 3H, J = 7.2 Hz, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.2 (2C≡O), 193.3 (C≡O), 164.1 (C═O), 158.8 (Phen), 148.0 (Phen), 138.5 (Phen), 128.7 (Phen), 126.3 (Phen), 126.0 (Phen), 66.1 (−OCH_2), 30.9 (H_3C-Phen), 28.7 (−OCH_2CH_2), 27.9 ($CH_2CH_2CH_3$), 22.3 (CH_2CH_3), 14.0 (CH_3). Data for **5**: Yield, 66%. MP 210–13 °C. Anal. Calcd. for $C_{23}H_{23}N_2O_6Re$. 0.20 CH_2Cl_2: C, 44.47%; H, 3.76%; N, 4.47%. Found: C, 44.77%; H, 3.44%; N, 4.57%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2022s, 1918s, 1894s; ν(C═O) 1661 m, br. ^{1}H NMR ($CDCl_3$, δ): 9.39 (dd, 2H, J = 5.0, 1.3 Hz), 8.70 (dd, 2H, J = 8.6, 1.3 Hz), 7.83 (dd, 2H, J = 8.6, 5.0 Hz), 3.71 (t, 2H, J = 7.1 Hz, −OCH_2), 2.80 (s, 3H, H_3C-Phen), 1.41 (quint, 2H, J = 7.2 Hz, −OCH_2CH_2), 1.22–1.11 (m, 4H, −$CH_2CH_2CH_3$), 0.78 (t, 3H, J = 7.2 Hz, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.8 (2C≡O), 193.5 (C≡O), 159.1 (C═O), 152.5 (Phen), 146.4 (Phen), 135.0 (Phen), 131.5 (Phen), 131.1 (Phen), 125.4 (Phen), 66.3 (−OCH_2), 28.8 (−OCH_2CH_2), 28.0 ($CH_2CH_2CH_3$), 22.4 (CH_2CH_3), 15.4 (H_3C-Phen), 14.0 (CH_3). Data for **6**: Yield, 72%. MP 150–52 °C. Anal. Calcd. for $C_{33}H_{27}N_2O_6Re$: C, 54.02%; H, 3.71%; N, 3.82%. Found: C, 53.95%; H, 3.50%; N, 3.84%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2022s, 1919s, 1894s; ν(C═O) 1660 m, br. ^{1}H NMR ($CDCl_3$, δ): 9.49 (d, 2H, J = 5.3 Hz, Phen), 8.05(s), 7.78 (d, 2H, J = 5.3 Hz, Phen), 7.63–7.60 (m, 6H, C_6H_5), 7.56–7.54 (m, 4H, C_6H_5), 3.80 (t, 2H, J = 7.1 Hz, −OCH_2), 1.49 (quint, 2H, J = 7.3 Hz, −OCH_2CH_2), 1.22–1.11 (m, 4H, −$CH_2CH_2CH_3$), 0.80 (t, 3H, J = 6.9 Hz, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.7 (2C≡O), 193.6 (C≡O), 159.1 (C═O), 153.1 (Phen), 151.2 (Phen), 147.7 (Phen), 135.4 (C_6H_5), 129.8 (C_6H_5), 129.4 (C_6H_5), 129.1 (C_6H_5), 128.7 (Phen), 125.7

(Phen), 125.4 (Phen), 66.3 ($-OCH_2$), 28.7 ($-OCH_2CH_2$), 27.9 ($CH_2CH_2CH_3$), 22.3 (CH_2CH_3), 13.9 (CH_3). Data for **7**: Yield, 83%. MP 166–69 °C. Anal. Calcd. for $C_{35}H_{31}N_2O_6Re$. 0.60 CH_2Cl_2: C, 52.60%; H, 3.99%; N, 3.45%. Found: C, 52.67%; H, 3.66%; N, 3.51%. IR (CH_2Cl_2, cm^{-1}): ν(C≡O) 2022s, 1914s, 1893s; ν(C═O) 1661 m, br. ^1H NMR ($CDCl_3$, δ): 7.85 (s, 2H, Phen), 7.67(s, 2H, Phen), 7.58–7.56 (m, 6H, C_6H_5), 7.51–7.48 (m, 4H, C_6H_5), 3.65 (t, 2 H, $J = 7.1$ Hz, $-OCH_2$), 3.41 (s, H_3C-Phen), 1.36 (quint, 2H, $J = 7.1$ Hz, $-OCH_2CH_2$), 1.18–1.07 (m, 4H, $-CH_2CH_2CH_3$), 0.77 (t, 3H, $J = 7.1$ Hz, CH_3). ^{13}C NMR ($CDCl_3$, δ): 197.4 (2C≡O), 193.6 (C≡O), 163.3 (C═O), 158.9 (Phen), 151.0 (phen), 148.9 (Phen), 136.0 (C_6H_5), 129.6 (C_6H_5), 129.4 (C_6H_5), 129.0 (C_6H_5), 127.1 (Phen), 126.2 (Phen), 124.2 (Phen), 66.2 ($-OCH_2$), 31.2 (H_3C-Phen), 28.8 ($-OCH_2CH_2$), 28.0 ($CH_2CH_2CH_3$), 22.4 (CH_2CH_3), 14.0

[6] *Crystal data for* **1**: $C_{19}H_{19}N_2O_6Re$, $M = 557.56$, orange needle, $0.07 \times 0.08 \times 0.12$ mm^3, monoclinic, space group $P2_1/n$ (No. 14), $a = 6.3714$ (3) Å, $b = 17.6930$ (7) Å, $c = 16.9114$ (7) Å, $\beta = 91.712$ (2)°, $V = 1905.56$ (14) $Å^3$, $Z = 4$, $T = 200$ (2) K, 23826 reflections total, 5559 unique, 4296 observed, number of variables = 337, number of restraints = 293, $R = 0.0303$, $R_w = 0.0767$, and goodness-of-fit = 1.038. The pentylcarbonato ligand was treated with a two-site disorder model with refined site occupancy factors of 0.51 (2) and 0.49 (2), respectively. *Crystal data for* **6**: $C_{33}H_{27}N_2O_6Re$, $M = 733.77$, yellow blade, $0.05 \times 0.18 \times 0.56$ mm^3, monoclinic, space group Pn (No. 7), $a = 12.1682$ (7) Å, $b = 13.7618$ (8) Å, $c = 18.6496$ (12) Å, $\beta = 90.997$ (3)°, $V = 3122.5$ (3) $Å^3$, $Z = 4$, $T = 296$ (2) K, 30766 reflections total, 8648 unique, 8282 observed, number of variables = 885, number of restraints = 368, $R = 0.0240$, $R_w = 0.0548$, and goodness-of-fit = 1.056. There are two independent molecules in the asymmetric unit of 6. Both of those molecules contain disordered pentylcarbonato ligands which were treated with two-site disorder models. The refined site occupancy factors were 0.52 (2) and 0.48 (2) for the major and minor components of the disorder in one of the two molecules and 0.63 (2) and 0.37 (2) in the other.

[7] (a) S.F. Haddad, J.A. Marshall, G.A. Crosby, B. Twamley, Acta Crystallogr. E58 (2002) m559–m561;
(b) D.K. Orsa, G.K. Haynes, S.K. Pramanik, M.O. Iwunze, G.E. Greco, D.M. Ho, J.A. Krause, D.A. Hill, R.J. Williams, S.K. Mandal, Inorg. Chem. Commun. 11 (2008) 1054–1056.

[8] See reference 7(b) above and the references 6, 12–14 cited in reference 7(b).

[9] (a) For Trypan Blue assay, see:D.K. Orsa, G.K. Haynes, S.K. Pramanik, M.O. Iwunze, G.E. Greco, J.A. Krause, D.M. Ho, A.L. Williams, D.A. Hill, S.K. Mandal, Inorg. Chem. Commun. 10 (2007) 821–824;
(b) For MTT assay, see:A.S. Azmi, S. Ali, S. Banerjee, B. Bao, M. Maitah, S. Padhye, P.A. Philip, R.M. Mohammad, F.H. Sarkar, Am. J. Transl. Res. 3 (2011) 374–382 and the references 7 and 8 cited therein.

[10] A.N. Glazer, K. Peck, R.A. Mathies, Proc. Natl. Acad. Sci. U. S. A. 87 (1990) 3851–3855.

[11] J.L. Kgokong, J.M. Wachira, Eur. J. Pharm. Sci. 12 (2001) 369–376.