[ReO(N_2O_2)X] Complexes: "4 + 1"?

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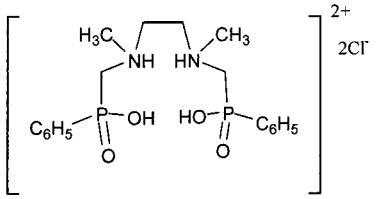
[ReO(ppme)X] (where $ppme^{2-}$ is 2,5-diazo-*N*,*N*′-dimethylhexyl-1,6-bis(phenylphosphinate), X = $Br_{0.3}Cl_{0.7}$) has been synthesized via a substitution reaction and structurally characterized. The coordination geometry is a distorted octahedron and one phosphinate coordinates *cis* and the other *trans* to the oxo O atom. This coordination mode is conserved in all [ReOppmeX] complexes synthesized in this study. [ReO(ppme)Cl] has been prepared by a reduction/complexation reaction from [NH_4][ReO_4]. [ReO(ppme)Cl] reacts with thiocyanate and benzene thiolate forming [ReO(ppme)X] (X = $^-$NCS, $^-SC_6H_5$), but the one-pot synthesis of the respective ternary thiolate complexes from perrhenate was not successful. The reduction/complexation reaction of a thiol, H_2ppmeCl_4, and perrhenate resulted in the formation of [H_3ppme][$ReO(SR)_4$], the reaction of which with [ReO(ppme)Cl] does not lead to [ReO(ppme)SR] in high yields.

Introduction

The resurgence of interest in rhenium chemistry partially stems from its radiopharmaceutical applications. Rhenium is similar to technetium, whose radionuclide (^{99m}Tc) is the workhorse of diagnostic nuclear medicine;[1−13] also, the radioisotopes ^{186}Re and ^{188}Re, which have suitable β-emitting properties, are being investigated for potential use in therapeutic nuclear medicine.[4,6,8] For example, a ^{186}Re complex with hydroxyethylidene diphosphonate (HEDP) has been proven to be beneficial in clinical trials for the palliation of bone pain.[4,6,14]

Following up on a study of tripodal amine phosphinate ligands and their complexes with lanthanides and group 13 metals, we made H_4ppmeCl_2, an N_2O_2 donor set amine phosphinate ligand for Re^V=O or Tc^V=O complexation.[15,16] Volumes of data exist on Re/Tc=O complexes with tetradentate N_2O_2 ligands, but most studies have been carried out with Schiff base or amine phenolate/enolate systems.[5,17−23] The complexes are usually hydrolytically sensitive, a factor attributed sometimes to the instability of Schiff base imine linkages. Also, the O donors in these ligands are mostly phenolates or enolates, both of which bind well under basic conditions. To our knowledge, no N_2O_2 ligands with carboxylate, phosphonate, or phosphinate O donors, i.e., those that bind under neutral or acidic conditions, have been successfully complexed to this M^V=O core. Given the hydrolytic instability of Tc and ease of oxidation of Re at high pH (where the phenolates and enolates binds best), the incorporation of phosphinates should introduce a bias for the ligand to coordinate in low pH reaction conditions, favorable to both the reduction of the metal ion and the stability of the complex.



H_4ppmeCl_2

We are also interested in ternary complexes. Dianionic N_2O_2 ligands usually complex M^V=O with an additional alcoholate, halide, or bridging oxo ligand, forming overall neutral complexes.[5,17−23] In light of a series of successful "3 + 1" complexes, in which a monodentate thiolate, bearing a receptor moiety, complements a tridentate NS_2 or S_3 donor set ligand,[7,24−27] we discuss here the potential of N_2O_2 donors to form "4 + 1"

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complexes with monodentate thiolates. A known problem in the "3 + 1" complexes is that the monodentate thiolate is easily demetalated by endogenous thiolate ligands (e.g., glutathione) and a tetradentate co-ligand could potentially make a complex which has a saturated coordination sphere, therefore slowing the unwanted substitution reaction.

Experimental Section

Materials. *N*,*N*′-Dimethylethylenediamine, phenylphosphinic acid, 30% formaldehyde, 37% HCl, potassium thiocyanate, benzenethiol, 4-methoxythiophenol, lipophilic Sephadex LH-20, and tetrabutylammonium bromide were obtained from Aldrich, Alfa, Fisher, or Sigma and used without further purification. $[NH_4][ReO_4]$ was received as a gift from Johnson-Matthey. $[(C_4H_9)_4N][ReOBr_4]$[28] and $ReO(P(C_6H_5)_3)_2Cl_3$[29] were synthesized by literature methods.

Instrumentation. IR (infrared) spectra were recorded as KBr disks in the range 4000−500 cm^{-1} on a Mattson Galaxy Series 5000 FTIR spectrophotometer. Mass spectra (Cs^+, LSIMS (liquid secondary ion mass spectrometry)) were obtained on a Kratos Concept II H32Q with thioglycerol as the matrix. All ^1H NMR spectra were recorded on a Bruker AC-200E spectrometer at 200 MHz and are reported as δ in ppm downfield from TMS. All $^{31}P\{^1H\}$ NMR spectra were recorded on the same instrument at 81 MHz and are reported as δ in ppm downfield from external phosphoric acid.

HPLC. Experiments were performed with Waters 501 HPLC pumps, a Waters U6K injector, and a Waters Lambda-Max model 481 LC spectrophotometer, all interfaced to a PC. A Hamilton PRP-1 reverse phase column (15 cm) was used; all runs were isocratic using 50/50 acetonitrile/water as the eluent at a flow rate of 1.0 mL/min. Gradient experiments were performed but no extra peaks were found. After some of the experiments, acetonitrile or methanol was used to elute the column but no extra species were detected in 40 min. The experiments were performed with the detector set at 350, 475, 600, and 698 nm for each sample.

H_4ppmeCl$_2$. Phenylphosphinic acid (3.5 g, 25 mmol) and *N*,*N*′-dimethylethylenediamine (1.0 g, 11 mmol) were dissolved in 6 M HCl (40 mL). The solution was heated to reflux, and 37% formaldehyde (4.9 g, 57 mmol) was added dropwise over 20 min. The solution was refluxed for 4.5 h and then concentrated to yield a white solid, which was dissolved in methanol (200 mL), and diethyl ether (100 mL) was added to precipitate the white product. The yield was quantitative. Anal. Calcd (Found) for $C_{18}H_{28}Cl_2N_2O_4P_2$: C, 46.07 (46.27); H, 6.01 (6.24); N, 5.97 (5.86). Mass spectrum (LSIMS): *m*/*z* 397 ($[H_3ppme]^+$). $^{31}P\{^1H\}$ NMR (D_2O) δ: 19 (s). ^1H NMR (D_2O) δ: 7.8−7.4 (10 H, 2 sets of multiplets, PC_6H_5), 3.7 (4 H, s, ethylene), 3.5 (4 H, d, NCH_2P), 2.9 (6 H, s, NCH_3).

[ReO(ppme)X], X = Br$_{0.3}$/Cl$_{0.7}$. To a stirred ethanolic solution (10 mL) of H_4ppmeCl$_2$ (62 mg, 0.13 mmol) was added $[N(C_4H_9)_4][ReOBr_4]$ (100 mg, 0.13 mmol) dissolved in 10 mL of ethanol. A gray precipitate formed immediately but redissolved when triethylamine (63 mg, 0.63 mmol) was added dropwise. The blue solution was refluxed for 2 h and was concentrated. The concentrated solution was loaded onto a Sephadex LH-20 column and eluted with ethanol. The blue fraction was collected, concentrated, and dried under vacuum to yield 59 mg (∼ 70%). Mass spectrum (LSIMS): *m*/*z* 699 ($[ReO(ppme)Br + Na]^+$), 677 ($[ReO(ppme)Br + H]^+$), 655 ($[ReO(ppme)Cl + Na]^+$), 633 ($[ReO(ppme)Cl + H]^+$), 597 ($[ReO(ppme)]^+$). $^{31}P\{^1H\}$ NMR (CD_3CN) δ: 84 (two peaks, $\Delta\delta = 0.3$), 38 (two peaks, $\Delta\delta = 0.5$). A microcrystalline material precipitated when diethyl ether diffused into an ethanolic solution of the product. Single crystals precipitated from a CD_3CN solution made of the crystalline material.

[ReO(ppme)Cl]·H$_2$O. To a hot methanolic solution (10 mL) of H_4ppmeCl$_2$ (142 mg, 0.300 mmol) and $[NH_4][ReO_4]$ (157 mg, 0.586 mmol) was added triphenylphosphine (90 mg, 0.34 mmol). The mixture was heated for 20 h at 70 °C to yield a blue solution and a small amount of precipitate. The solution was decanted, concentrated, and dried under vacuum. The resultant blue residue was suspended in acetone, and the suspension was filtered. Diethyl ether was added liberally to the filtrate to precipitate the blue product, which was filtered out and dried to yield 180 mg (91.6%). A crystalline material formed on slow evaporation of an acetone/water solution of the product. Anal. Calcd (Found) for $C_{18}H_{26}ClN_2O_5P_2Re$: C, 33.26 (33.03); H, 4.03 (3.98); N, 4.31 (4.03). IR (cm^{-1}, KBr disk): 1206, 1199, 1124, 949, 931. Mass spectrum (LSIMS): *m*/*z* 633 ($[ReO(ppme)Cl + H]^+$), 597 ($[ReO(ppme)]^+$). $^{31}P\{^1H\}$ NMR (acetone-d_6): 84, 38. HPLC: peak maximum at 1.2 min.

[ReO(ppme)NCS]·CH$_3$OH. To a methanolic solution (3 mL) of [ReO(ppme)Cl]·H_2O (65 mg, 0.10 mmol) was added KSCN (11 mg, 0.11 mmol), resulting in immediate precipitation of a white salt. The supernatant was decanted and was allowed to stand at room temperature for 2 days upon which time more white precipitate was formed and subsequently filtered out. The filtrate was concentrated and dried. The isolated yield was very low (<10 mg). Anal. Calcd (Found) for $C_{20}H_{28}N_3O_6P_2ReS$: C, 34.98 (35.30); H, 4.11 (4.00); N, 6.12 (5.73). IR (cm^{-1}, KBr disk): 2060, 1206, 1123, 945, 923. Mass spectrum (LSIMS): *m*/*z* 656 ($[M + H]^+$), 597 ($[M - NCS]^+$). $^{31}P\{^1H\}$ (acetone-d_6) NMR δ: 79, 38. HPLC: peak maximum at 2.0 min.

[ReO(ppme)(SC$_6$H$_5$)]. Method A. [ReO(ppme)Cl]·H_2O (23 mg, 0.035 mmol) was dissolved in 1 mL of acetone-d_6, and KSC_6H_5 (8 mg, 0.05 mmol) was added but was not soluble. The mixture was heated at 70 °C for 40 h, during which time a white precipitate slowly formed. The supernatant was decanted and the ^{31}P NMR spectrum recorded.

Method B. ReO(ppme)Cl·H_2O (63 mg, 0.10 mmol) and $[H_3ppme][ReO(SC_6H_5)_4]$ (same preparation as $[H_3ppme][ReO(SC_6H_5OCH_3)_4]\cdot 2H_2O$, 20 mg, 0.019 mmol) were dissolved in 2 mL of CD_3CN with a few drops of D_2O. The mixture was heated at 70 °C for 40 h, upon which time ReO(ppme)(SC_6H_5), ReO(ppme)Cl, and $[H_3ppme][ReO(SC_6H_5)_4]$ were seen in the ^{31}P and ^1H NMR spectra. More $[H_3ppme][ReO(SC_6H_5)_4]$ (a total of 48 mg, 0.046 mmol) was added in two portions, each followed by 20 h of heating. More D_2O was added, resulting in the formation of a black oily precipitate which was allowed to settle. The supernatant was decanted and more D_2O was added in order to precipitate the brown product. The solvent was further reduced by rotary evaporation and was decanted off. The brown product was dried under vacuum. The isolated yield was low (<10 mg). Anal. Calcd (Found) for $C_{24}H_{29}N_2O_5P_2ReS$: C, 40.85 (40.71); H, 4.14 (4.19); N, 3.97 (4.20). IR (cm^{-1}, KBr disk): 1200 (ν_{PO}), 1126(ν_{PO}), 952, 930. Mass spectrum (LSIMS): *m*/*z* 1473 ($[2M + H]^+$), 707 ($[M + H]^+$), 597 ($[M - C_6H_5S]^+$). $^{31}P\{^1H\}$ NMR (CD_3CN) δ: 74, 34. HPLC: peak maximum at 2.3 min.

[H$_3$ppme][ReO(SC$_6$H$_4$OCH$_3$)$_4$]·2H$_2$O. To a solution of H_4ppmeCl$_2$ (94 mg, 0.20 mmol) and $[NH_4][ReO_4]$ (54 mg, 0.20 mmol) in 5 mL of methanol was added $HSC_6H_4OCH_3$ (180 mg, 1.29 mmol). The solution immediately turned dark brown and a red/brown microcrystalline material precipitated soon afterward. After a few hours, the crystals were filtered out, washed with methanol, and dried under vacuum to yield (199 mg, 86%). Anal. Calcd (Found) for $C_{46}H_{59}N_2O_{11}P_2ReS_4$: C, 46.34 (46.59); H, 4.99 (4.85); N, 2.35(2.35). IR (cm^{-1}, KBr disk): 1589, 1174 (ν_{PO}), 959 (ν_{ReO}). $^{31}P\{^1H\}$ NMR (DMSO-d_6) δ: 25. ^1H NMR (DMSO-d_6) δ: 7.9−7.4 (10 H, 2 sets of multiplets, PC_6H_5), 7.4 and 6.9 (8 H each, 2 sets of doublets, SC_6H_4O), 3.8 (12 H, s, OCH_3), 3.6−3.4 (8 H, overlapped methylene H), 2.7 (6 H, s, NCH_3).

[ReO(ppme)(SC$_6$H$_4$OCH$_3$)]. Same as method B for [ReO(ppme)(SC_6H_5)], and $[ReO(SC_6H_4OCH_3)_4][H_3ppme]$ (a total of 54 mg, 0.046 mmol, in 4 portions) was used. Anal. Calcd (Found) for $C_{25}H_{31}N_2O_6P_2ReS$: C, 40.81 (40.91); H, 4.25 (4.49); N, 3.81(3.50). IR (cm^{-1}, KBr disk): 1198 (ν_{PO}), 1122 (ν_{PO}), 950, 930. Mass spectrum (LSIMS): *m*/*z* 1473 ($[2M + H]^+$), 737 ($[M + H]^+$), 597 ($[M - C_7H_7OS]^+$). $^{31}P\{^1H\}$ NMR (acetone-d_6) δ: 80, 38. HPLC: peak maximum at 2.3 min.

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Table 1. Selected Crystallographic Data for [ReO(ppme)X] X = $Br_{0.29}/Cl_{0.71}$[a]

formula	$C_{18}H_{24}Br_{0.29}Cl_{0.71}N_2O_5P_2Re$
fw	644.90
cryst syst	tetragonal
space group	$P4_1$
A, Å	12.898(1)
C, Å	13.456(2)
V, Å^3	2238.4(5)
Z	4
ρ_{calc}, g/cm^3	1.913
F(000)	1252.88
T, °C	21.0
radiation	Mo Kα (λ = 0.710 69 Å)
μ, cm^{-1}	62.09
transmission factors	0.653−1.000
$2\theta_{max}$	65.0°
total reflections	4517
unique reflections	4207
reflections with $I > 3\sigma(I)$	2489
no. of variables	272
R; R_w	0.032; 0.026

[a] $R = \sum||F_o| - |F_c||/\sum|F_o|$, $I > 3\sigma(I)$; $R_w = (\sum_w(|F_o| - |F_c|)^2/\sum_w(F_o^2))^{1/2}$.

X-ray Crystallographic Analysis. A blue prismatic crystal of [ReO(ppme)$Br_{0.29}Cl_{0.71}$] was mounted on a glass fiber for data collection on a Rigaku AFC6S diffractometer at 21 °C (Table 1). The data were collected using the $\omega-2\theta$ scan technique to a maximum 2θ value of 65° and were corrected for Lorentz and polarization effects. A correction for secondary extinction was applied (coefficient = 3.78(10) × 10^{-7}). The structure was solved by heavy-atom Patterson methods[30] and expanded using Fourier techniques.[31] The halide position was occupied by Cl or Br. The halides were resolved, and the population parameter of the most abundant (Cl) was refined. The non-hydrogen atoms were refined anisotropically, and the hydrogen atoms were fixed in calculated positions with the C−H = 0.98 Å.

Results and Discussion

Under anhydrous conditions and in the presence of a base, H_4ppmeCl_2 reacts with $[(C_4H_9)_4N][ReOBr_4]$ to form [ReO(ppme)X] (X = Br/Cl), a blue mixture of halide complexes which are difficult to separate. In contrast, ammonium perrhenate can be reduced with triphenylphosphine in the presence of the ligand to form [ReO(ppme)Cl] in a vial and in high yield. Elemental analysis of the blue crystalline material agrees with its formulation, LSIMS shows $[M + H]^+$ and $[M - Cl]^+$ peaks, and the IR spectrum shows prominent PO peaks as well as two possible $\nu_{Re=O}$ at 931 and 949 cm^{-1} (identification of the Re=O peak was not attempted). The ^{31}P NMR spectrum exhibits two resonances at 84 and 38 ppm, indicating a drastic difference in the coordinating phosphinates: one *cis* and the other *trans* to the oxo O atom (vide infra). Correspondingly, the ^{1}H NMR spectrum shows that (1) the molecule is asymmetric, (2) the two sides of the ligand are in markedly different chemical environments, and (3) the molecule is rigid at room temperature.

The reduction/complexation reaction is interesting. In a 1:1:1 methanolic mixture of $[NH_4][ReO_4]$, triphenylphosphine, and H_4ppmeCl_2, [ReO(ppme)Cl] formed almost exclusively (as detected by ^{31}P NMR spectroscopy). Triphenylphosphine oxide and a very small amount of triphenylphosphine-related complexes were also formed. The presence of excess triphenylphosphine impeded the substitution reaction because $ReO(P(C_6H_5)_3)_2Cl_3$ was formed and remained intact for days in the reaction mixture. Similarly, $ReO(P(C_6H_5)_3)_2Cl_3$ did not react with ppme in a simple substitution fashion.

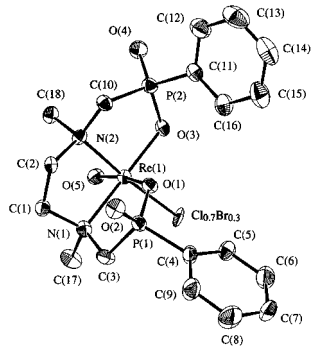

Figure 1. ORTEP drawing of ReO(ppme)($Br_{0.3}Cl_{0.7}$). Thermal ellipsoids for the non-hydrogen atoms are drawn at the 33% probability level.

Table 2. Selected Bond Lengths (Å) and Angles (deg) in [ReO(ppme)X] X = $Br_{0.29}/Cl_{0.71}$

Re−O(5)	1.666(6)
Re−N(1)	2.187(7)
Re−N(2)	2.139(6)
Re−O(3)	1.995(6)
Re−O(1)	2.031(5)
Re−Br/Cl	2.48(1)/2.38(1)
Br/Cl−Re−O(5)	96.0(4)/96.2(4)
N(1)−Re−O(5)	88.8(3)
N(2)−Re−O(5)	92.1(3)
O(3)−Re−O(5)	109.1(3)
O(1)−Re−O(5)	166.5(3)
N(1)−Re−N(2)	83.3(3)
N(1)−Re−O(3)	159.7(2)
N(1)−Re−O(1)	78.3(2)
N(1)−Re−Br/Cl	97.2(5)/98.9(4)
N(2)−Re−O(1)	82.6(2)
N(2)−Re−O(3)	86.6(2)

Single crystals of ReO(ppme)X (X = Br/Cl) precipitated from a CD_3CN solution of the complex mixture, and the X-ray crystallographic analysis confirmed the structure proposed based on NMR results (Figure 1 and Table 2). The Re center is coordinated by the N_2O_2 ligand and oxo O and halide atoms, forming a distorted octahedron. The halide atom is coordinated *cis* to the oxo atom, and the two *N*-methyl groups are *syn* to the oxo O atom. The *cis* coordination of the halide atom to the oxo atom is common, and to our knowledge, it is the only mode of coordination in ReO(N$_2$O$_2$)Cl complexes.[22,23] The distortion, where the ligand coordinating sites squeeze toward each other and bend away from the oxo O, is also typical of a ReO(N$_2$O$_2$)X complex. The Re=O bond is 1.666 Å and is at the short end of the reported values; the Re−N, Re−O, and Re−Cl bond lengths are within the expected ranges.[20,22,23,32,33]

Unlike a few other ReO(N$_2$O$_2$) complexes, in which coordination modes vary and a few diasteromers persist, one ReO(ppme)X diastereomer forms preferentially. Also, the halide position is not labile: simple solvolysis of the halide in CD_3OD or D_2O was not seen (by ^{31}P NMR spectroscopy) even over a day or two. (The complex, however, decomposes in a heated CD_3OD/D_2O mixture over a few weeks.) These features suggest an excellent opportunity for conjugating the $[ReO(ppme)]^+$ unit

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to a monodentate ligand through a halide substitution reaction. Following the success of the aforementioned series of "3 + 1" complexes,[7,24−27] we probed $[ReO(ppme)]^+$ as a potential "4 + 1" system.

ReO(ppme)Cl reacts with KSCN or KSC_6H_5 to form [ReO(ppme)(NCS)] or $[ReO(ppme)(SC_6H_5)]$, respectively. $[ReO(ppme)(SC_6H_4OCH_3)]$ was also made but from a different route (vide infra). The products were characterized by LSIMS and IR and ^{31}P NMR spectra. Their purities were checked by elemental analysis and HPLC. The IR spectra of all the [ReO(ppme)X] complexes are similar. Diagnostic ν_{PO} and $\nu_{Re=O}$ stretches are evident in every complex, but vary slightly in frequency. Additional ligand peaks are seen for the respective coligand. The NCS^- is likely to be N-bound in [ReO(ppme)NCS] based on analogous ν_{CN} values.[34] (The CN stretching frequencies in N-bonded complexes are near 2050 cm^{-1} and that in S-bonded complexes are near 2100 cm^{-1}, but CN stretching alone is not definitive evidence in such determination.[34]) The (+)LSIMS spectra of all the ReO(ppme)X complexes invariably exhibit prominent $[M + H]^+$ and $[M - X]^+$ peaks. The ^{31}P NMR spectra show two peaks at ~80 and ~35 ppm, and the ^1H NMR spectra display similar resonances resulting from the ppme backbone. These features demonstrate that the complexes share the same structure with respect to ReO(ppme) and only differ in X coordination. These complexes also have similar solubilities in water and organic or mixed solvents. Related to this, HPLC experiments show that these complexes are similarly retained on a reverse phase column.

^{31}P NMR experiments following these reactions suggested that the substitutions were reasonably simple and that only the products and the free ligand (ppme) were found in the mixture. The free ligand formation can be explained by decomposition of the complex and/or failure of $ppme^{2-}$ to compete with the thiol. This demetalation of $ppme^{2-}$ is ominous in a one-pot synthesis of the ternary complexes. In a radiopharmaceutical "kit" formulation where perrhenate (or pertechnetate) would be reduced with both of the ligands in excess, formation of ternary complexes would require the ligands to complement, rather than to compete with, each other.

An attempted one-pot synthesis of the ternary complex [ReO(ppme)SR] resulted in the formation of $[H_3ppme][ReO(SR)_4]$ ($^-SR = {}^-SC_6H_4OCH_3$). $[NH_4][ReO_4]$ reacts rapidly with excess HSR in the presence of $H_4ppmeCl$ in methanol, and the red crystalline tetrathiolate complex precipitated in high yields. The immediate questions raised are whether the formation of the unwanted product is driven by its insoluble nature and whether it can be converted to the desired ternary complex. $[H_3ppme][ReO(SR)_4]$ was dissolved in CD_3CN and heated or left in the open air for a few days, but it did not convert to the "4 + 1" complex, even after addition of KOH. Thus, this complex is very stable. Aside from the minor misfortune that $ppme^{2-}$ does not coordinate to the metal, this material is interesting. $[ReO(SR)_4]^-$ complexes have been studied extensively, but to our knowledge, one-pot syntheses from perrhenate have not been reported.[35,36] Recently, thiols conjugated to a biologically active molecule (BAM) have been fixed onto solid supports and then reacted with Tc precursors to form Tc−thiolate−BAM conjugates in solution, so that no free BAM was actually present in solution.[37,38] This approach reduced competition of free BAM binding to the receptor. In light of this development and because $[H_3ppme][ReO(SR)_4]$ has little solubility in water or alcohol, it could be used as a solid thiol source in forming ternary complexes.

Reactions of ReO(ppme)Cl with $[H_3ppme][ReO(SR)_4]$, however, are slow. Biphasic reaction of solid $[H_3ppme][ReO(SR)_4]$ and [ReO(ppme)Cl] in methanol produces little [ReO(ppme)(SR)] even after 2 days at 70 °C; also, when both starting materials were dissolved in acetonitrile the formation of [ReO(ppme)(SR)] took days of heating. When the reaction was monitored by ^{31}P NMR, the coexistence of $[ReO(SR)_4]^-$, ReO(ppme)(SR), and [ReO(ppme)Cl] was evident, and the ratio of the species changed when more $[ReO(SR)_4]^-$ was added. Thus, $[ReO(SR)_4]^-$ and [ReO(ppme)Cl] species exist in equilibrium with [ReO(ppme)SR] and some side product, and the equilibrium does not lie heavily toward the formation of the ternary thiolate complexes. This equilibrium precludes the actual use of "4 + 1" complexes in nuclear medicine.

Conclusions

[ReO(ppme)Cl] has been synthesized and a [ReO(ppme)X] ($X = Br_{0.3}Cl_{0.7}$) sample has been structurally characterized. Substitution of X with thiocyanate and aromatic thiolates was successful, but the one-pot synthesis of the respective ternary thiolate complexes was not. Reduction/complexation reaction of thiol, $H_2ppmeCl_4$, and perrhenate resulted in the formation of $[H_3ppme][ReO(SR)_4]$, the reaction of which with ReO(ppme)Cl does not lead to [ReO(ppme)SR] in high yields.

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Supporting Information Available: X-ray crystallographic files in CIF format for structure [ReO(ppme)X] ($X = Br_{0.3}Cl_{0.7}$). This material is available free of charge via the Internet at http://pubs.acs.org.

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