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Neutral ‘3 + 1’ mixed-ligand oxorhenium(V) complexes with tridentate [S,N,S] chelates and aminoalkanethiols: synthesis, characterization and structure determination ‡

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‘3 + 1’ Oxorhenium(V) complexes [ReO(SN(R′)S)(SR)] (R′ = Me, Et, Pr or Bu; SR = aminoalkane thiolate) have been synthesized by ligand exchange at *trans*-trichloromonooxo-bis(triphenylphosphine)rhenium(V) with a mixture of HSN(R′)SH and RSH in alkaline methanolic solution. The complexes were purified by column chromatography and characterized by elemental analysis, mass and IR spectroscopy and for selected compounds by ^{1}H NMR spectroscopy. The structures of those complexes have been determined by X-ray diffraction analysis and revealed a change in the co-ordination geometry from square pyramidal to trigonal bipyramidal, depending on the chelating (SN(R′)S) moiety. The alkyl group (R′) was found to be arranged “*syn*” to the oxorhenium group.

Introduction

Co-ordination compounds of technetium and rhenium play an important role in the search for new radiopharmaceuticals for use in nuclear medicine.[1–4] The γ-emitter ^{99m}Tc has widely been used as the most important nuclide for diagnostic purposes for many years, and ^{186}Re and ^{188}Re attract increasing interest, since these nuclides emit β^- particles with therapeutically useful energies. While all isotopes of technetium are radioactive, chemically analogous complexes of non-radioactive rhenium are frequently employed in model studies. These complexes are used as references to identify the analogous technetium complexes *e.g.* by HPLC comparison and may be useful as therapeutics.

Present efforts aim to develop new co-ordination compounds for imaging the brain *in vivo*, which requires being able to cross the blood brain barrier (BBB), and to be bound by receptor sites. Such studies favor oxotechnetium(V) and oxorhenium(V) complexes containing amine groups,[5–8] since the presence of a basic amino group in the compound is a prerequisite for binding at receptor sites.

Our investigations focus on the relationship between molecular structure, lipophilicity parameters and brain uptake of a series of systematically altered ‘3 + 1’ mixed ligand complexes, where the equatorial co-ordination sphere is formed by a tridentate chelate ligand together with a monodentate amino group bearing a thiolate ligand. We consider this type of complex as well suited because they can be varied at the chelate site as well as the amine position. This enables us to introduce specific pharmacophores possessing amino groups by simple monodentate co-ordination *via* a thiolato sulfur. However, efforts to synthesize the desired ‘3 + 1’ compounds in a one pot reaction starting from the precursor [ReOCl$_3$(PPh$_3$)$_2$] are hampered by the parallel formation of *cis*-dioxorhenium(V) complexes of the general type [ReO$_2$(SN)(PPh$_3$)] (Fig. 1).[9] While a ratio of monodentate ligand (alkane-SH) : tridentate ligand (HSXSH, X = S or NR) : [ReOCl$_3$(PPh$_3$)$_2$] precursor of 4 : 1 : 1 normally increases the yield of the ‘3 + 1’ complexes, we observed a significant amount of the *cis*-dioxorhenium(V) complex when using *N*-(2-dialkylamino)ethanethiol as a monodentate ligand instead of a simple alkanethiol. Since the formation of the *cis*-dioxorhenium(V) complex is due to the reaction of the rhenium(V) precursor with traces of water associated with the precursor and the *N*-(2-dialkylamino)-ethanethiol ligand, using thoroughly dried [ReOCl$_3$(PPh$_3$)$_2$] precursor and a strict 1 : 1 : 1 stoichiometric ratio of monodentate ligand : tridentate ligand : [ReOCl$_3$(PPh$_3$)$_2$] precursor, are prerequisite to achieve higher ‘3 + 1’ complex yields over the *cis*-dioxorhenium(V) complex.

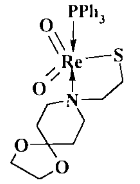

Fig. 1 Complex [ReO$_2$(SN)(PPh$_3$)], where the amine thiol is bidentate co-ordinated to the *cis*-dioxorhenium(V) core.

The use of tridentate (SN(R′)S) ligands offers the opportunity to modify the lipophilicity of the complex by varying the alkyl chains, while retaining the receptor binding properties. ‘3 + 1’ Mixed ligand rhenium complexes containing tris-chelating ligands such as [SOS] and [SSS] with alkane- and arenethiolates as monodentate ligands have been described in this journal.[10] Preliminary pharmacological studies on some technetium complexes of these types have been described earlier, but no details on synthesis have been published.[11]

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‡ Electronic supplementary information (ESI) available: analytical and spectroscopic data. See http://www.rsc.org/suppdata/dt/b0/b001600o/

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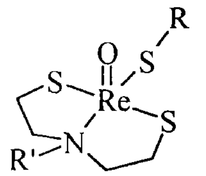
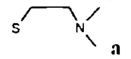
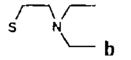
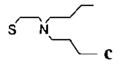
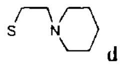
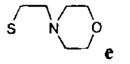
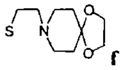
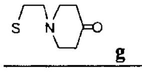
The present report discusses the preparation and characterization of new oxorhenium(V) complexes, as well as crystal structure determinations for selected compounds, of the general formula [ReO(SN(R′)S)(SR)]. HSN(R′)SH symbolizes the tridentate dithiol ligand $HSCH_2CH_2N(R')CH_2CH_2SH$ where R′ = Me (**1**), Et (**2**), Pr (**3**) or Bu (**4**). RSH represents dialkylaminoethanethiols that serve as monodentate ligands and are designated by letters. A general formula and numbering scheme for the resulting complexes that contain both ligands is given in Scheme 1.

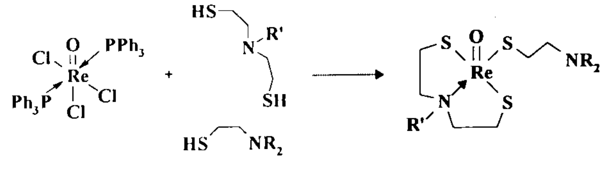


R' / R	-methyl 1	-ethyl 2	-propyl 3	-*n*-butyl 4
	1a	2a	3a	4a
	1b	2b	3b	4b
	1c	2c	3c	4c
	1d	2d	3d	4d
	1e	2e	3e	4e
	1f	2f	3f	-
	1g	2g	3g	-

Scheme 1 General formula and numbering scheme of prepared ‘3 + 1’ oxorhenium(V) complexes.

Results and discussion

Neutral ‘3 + 1’ oxorhenium(V) complexes [ReO(S(NR′)S)(SR)], bearing the tridentate chelate ligand and *N*-(2-dialkylamino)ethanethiol derivatives, have been obtained according to Scheme 2, by adding a 1 : 1 molar ratio mixture of the ligands to a stirred methanolic suspension of the precursor $[ReOCl_3(PPh_3)_2]$ at 70 °C. In order to complete the reaction procedure in an appropriate time the mixture was briefly refluxed in methanol. Addition of an external base to the reaction mixture seems to be essential. The compounds can be synthesized by employing methanol or dichloromethane as solvent, and sodium acetate or triethylamine as the base. The tendency to form *cis*-dioxorhenium(V) compounds involving the bidentate donor set of the aminoalkanethiol ligands, as mentioned above, was always observed but could be minimized by the use of exact 1 : 1 : 1 ratios and dried reactants and solvents. These conditions lead to pure products but moderate yields. Attempts to prepare the compounds using $[NBu_4][ReOCl_4]$, the preferred precursor for the preparation of [SOS] and [SSS] tridentate ligand bearing complexes,[10] resulted in even lower yields.



Scheme 2 Pathways to the ‘3 + 1’ co-ordinate rhenium(V) complexes.

The rhenium compounds were purified by column chromatography on silica gel with chloroform as the mobile phase. However, chloroform–methanol (19 : 1) was used for eluting the less lipophilic complexes (**1a**, **1b**, **1d**, **2a**, **2b**, **3a**, **3b**). After removing the solvent, crystalline complexes were obtained from dichloromethane by addition of a 1 : 1 quantity of methanol containing two drops of water, followed by slow evaporation. All of these complexes are very soluble in organic solvents such as trichloromethane, dichloromethane, acetonitrile; slightly soluble in methanol, ethanol; very slightly soluble in diethyl ether and almost insoluble in *n*-heptane and water. Heating the compounds in any of these solvents for several hours did not result in decomposition.

Elemental analysis of the complexes confirms their formulation comprising a 1 : 1 molar ratio of the tridentate and monodentate ligands, with a M=O core. The ^1H NMR spectroscopic investigations showed signal patterns typical for the presence of both ligands in the proposed structure, but the exact assignment of the signals is complicated by the overlapping of many of the methylene protons (data not shown).

Mass spectra with chemical ionization (pos./neg.) in addition to electrospray identified the postulated structures as the ions of the highest mass. Complexes **1a**–**4g** are ionizable by the described CI (negative) procedure, which results in simple spectra without fragmentation of the sample. The isotopic patterns of $^{185}Re/^{187}Re$ were found for all of the proposed complexes. IR-stretching bands in the range from 940 to 960 cm^{-1}, typical for the Re=O absorption, were obtained for the complexes. UV spectra showed absorbances at 580, 397, 364, 305, 252 and 216 nm. All yields, elemental analysis, melting points and spectroscopic data are summarized in Tables A and B in the Electronic Supplementary Materials.

A detailed discussion of the structural investigations is given for three representative complexes (**1e**, **2f** and **3g**).

Complex 1e

An ideal isotope pattern for rhenium complexes was observed in the mass spectrum obtained for **1e**. The molecular ion $[M]^-$ is the highest peak observed with no fragments detected. A strong Re=O stretching vibration at 950 cm^{-1} was measured for **1e** in the IR spectrum. Compared to the $[ReOCl_3(PPh_3)_2]$ precursor (980 cm^{-1}), this vibration is shifted to shorter wavenumbers.

The crystal structure determination of complex **1e** clearly reveals the formation of a distorted square pyramidal complex (Fig. 2, Table 1). Three sulfur donors and one nitrogen donor form the base plane and a short rhenium–oxygen bond form the apex of the pyramid. The Re is located 0.994 Å above the basal plane. The parameter τ[12] introduced to classify fivefold co-ordinate complexes as ideally trigonal bipyramidal ($\tau = 1$) or square pyramidal ($\tau = 0$) was determined to be 0.47. The alkyl substituent of the co-ordinated nitrogen is “*syn*” to the oxygen of the Re=O group. Analysis of the crystallographic data of

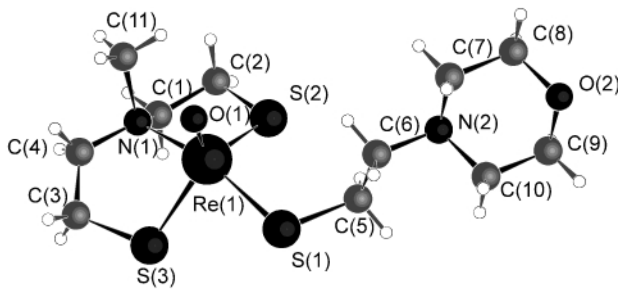


Fig. 2 Crystal structure of complex **1e**.

Table 1 Selected bond lengths (Å) and angles (°) for complex **1e** with estimated standard deviations (e.s.d.s) in parentheses

Re–O(1)	1.663(10)	S(3)–C(3)	1.80(3)
Re–N(1)	2.153(12)	C(3)–C(4)	1.44(4)
Re–S(2)	2.270(3)	N(1)–C(4)	1.45(2)
Re–S(3)	2.278(4)	N(1)–C(1)	1.47(2)
Re–S(1)	2.293(3)	C(1)–C(2)	1.50(2)
S(1)–C(5)	1.805(13)	N(1)–C(11)	1.54(3)
O(1)–Re–N(1)	99.3(5)	C(5)–S(1)–Re	113.1(4)
O(1)–Re–S(2)	117.7(4)	C(2)–S(2)–Re	103.4(5)
N(1)–Re–S(2)	82.4(3)	C(3)–S(3)–Re	102.8(10)
O(1)–Re–S(3)	115.9(4)	C(4)–N(1)–C(1)	113.7(14)
N(1)–Re–S(3)	82.1(4)	C(4)–N(1)–C(11)	103.0(2)
S(2)–Re–S(3)	125.8(2)	C(1)–N(1)–C(11)	106.0(2)
O(1)–Re–S(1)	106.3(4)	C(4)–N(1)–Re	113.0(9)
N(1)–Re–S(1)	154.0(4)	C(1)–N(1)–Re	113.0(9)
S(2)–Re–S(1)	89.7(12)	C(11)–N(1)–Re	107.8(12)
S(3)–Re–S(1)	82.7(13)	N(1)–C(1)–C(2)	110.0(12)

Table 2 Selected bond lengths (Å) and angles (°) for complex **2f** with e.s.d.s in parentheses

Re–O(1)	1.698(4)	S(3)–C(7)	1.825(6)
Re–N(1)	2.225(5)	C(3)–C(4)	1.502(9)
Re–S(2)	2.269(2)	N(1)–C(3)	1.489(7)
Re–S(3)	2.302(14)	N(1)–C(5)	1.511(7)
Re–S(1)	2.292(14)	C(1)–C(2)	1.522(9)
S(1)–C(1)	1.827(6)	N(1)–C(2)	1.492(7)
O(1)–Re–N(1)	96.5(2)	C(7)–S(3)–Re	113.2(2)
O(1)–Re–S(2)	117.8(2)	C(1)–S(1)–Re	103.1(2)
N(1)–Re–S(2)	83.1(14)	C(4)–S(2)–Re	104.0(2)
O(1)–Re–S(3)	105.6(14)	C(2)–N(1)–C(3)	112.4(4)
N(1)–Re–S(3)	157.5(12)	C(2)–N(1)–C(5)	110.3(5)
S(1)–Re–S(2)	122.4(6)	C(3)–N(1)–C(5)	108.2(4)
O(1)–Re–S(1)	119.1(2)	C(3)–N(1)–Re	109.8(3)
N(1)–Re–S(1)	92.9(13)	C(5)–N(1)–Re	107.5(3)
S(2)–Re–S(3)	90.2(6)	C(2)–N(1)–Re	108.5(3)
S(3)–Re–S(1)	82.7(5)	N(1)–C(5)–C(6)	115.1(5)

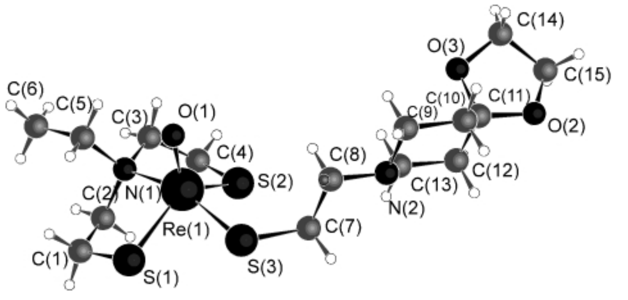


Fig. 3 Crystal structure of complex **2f**.

several '3 + 1' [ReO(S(NR′)S)(SR)][13–15] and tetradentate N_2S_2 oxorhenium(V)[15a,b,c] complexes does not show any contact interactions of the "*syn*" substituent with the oxo-group. The formation of the *syn* isomer is consistent with numerous reports of rhenium and technetium monooxo 3 + 1 and tetradentate N_2S_2 complexes wherein the "*syn*" isomer is either the exclusive or predominant (>90%) isomer formed.[13–15] The *syn* orientation may be the thermodynamically preferred geometry caused probably by a higher molecular orbital (MO) overlap of the donating nitrogen lone pair and the empty metal orbitals. The formation of the *anti* isomer is presumably due to kinetic trapping as this isomer is either absent or observed only as a minor constituent in N-substituted complexes of this kind.

Complex 2f

The molecular ion of complex **2f** in the mass spectrum shows the ideal isotopic pattern of ^{185}Re/^{187}Re. No other rhenium-containing fragments were detected. The IR spectrum shows the Re=O stretching vibration shifted to a shorter wavenumber of 944 cm^{-1}. Additionally, the typical strong vibrations of the ethylene glycol group of the monodentate ligand were detected at 1436.7 and 1466.8 cm^{-1}.

The crystal structural determination of complex **2f** (Fig. 3, Table 2) confirms that the basic structural features are similar to those of **1e**. The neutral nitrogen donor of the tris-chelating ligand and the S(3) donor (monodentate ligand) are shifted out of the former base plane to take up an axial position (N(1)–Re–S(3) 157.5° compared to N(1)–Re–S(1) 154.0° for **1e**), while the sulfur atoms S(1) and S(2) are shifted more out of the former equatorial base plane in the opposite direction. Thus, a new equatorial plane is formed by O(1), S(1), S(2) around the rhenium central atom and the 3-D structure is distorted to a trigonal bipyramid ($\tau = 0.59$). This phenomenon may be effected by the longer alkyl side chain of the tridentate ligand.

Complex 3g

The isotope pattern in the mass spectrum of complex **3g** was found identical to those of **1e** and **2f**. The molecular ion [M]$^-$ was the signal of the highest mass with no fragments detected. The IR spectrum revealed a Re=O stretching vibration at 951.0 cm^{-1}. Additionally, the strong vibration of the carbonyl group of the monodentate ligand was observed at 1713.9 cm^{-1}.

Table 3 Selected bond lengths (Å) and angles (°) for complex **3g** with e.s.d.s in parentheses

Re–O(1)	1.698(6)	S(3)–C(8)	1.825(9)
Re–N(1)	2.216(7)	C(3)–C(4)	1.519(13)
Re–S(2)	2.279(3)	N(1)–C(3)	1.498(11)
Re–S(3)	2.305(2)	N(1)–C(5)	1.500(11)
Re–S(1)	2.270(2)	C(1)–C(2)	1.489(9)
S(1)–C(1)	1.833(10)	N(1)–C(2)	1.511(7)
O(1)–Re–N(1)	95.2(3)	C(8)–S(3)–Re	109.9(3)
O(1)–Re–S(2)	119.5(3)	C(1)–S(1)–Re	103.5(3)
N(1)–Re–S(2)	83.6(2)	C(4)–S(2)–Re	103.3(3)
O(1)–Re–S(3)	104.9(2)	C(2)–N(1)–C(3)	110.7(7)
N(1)–Re–S(3)	159.7(2)	C(2)–N(1)–C(5)	108.9(7)
S(1)–Re–S(2)	122.6(10)	C(3)–N(1)–C(5)	110.0(7)
O(1)–Re–S(1)	117.4(3)	C(3)–N(1)–Re	108.7(5)
N(1)–Re–S(1)	83.8(2)	C(5)–N(1)–Re	108.5(5)
S(2)–Re–S(3)	84.1(9)	C(2)–N(1)–Re	110.0(5)
S(3)–Re–S(1)	89.3(9)	N(1)–C(5)–C(6)	117.9(7)

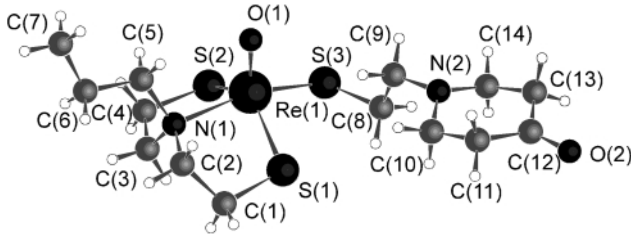
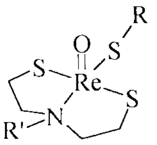


Fig. 4 Crystal structure of complex **3g**.

Structure determination of complex **3g** reveals the expected co-ordination mode for compounds such as [ReO(SNS)(S)] (Fig. 4, Table 3). The arrangement of oxygen, sulfur, nitrogen and the metal center is similar to those of **1e** and **2f**. The N(1)–Re–S(3) bond angle is larger (159.7°) than in **1e** and **2f** and the molecular structure is even more distorted to a trigonal bipyramid when compared to those of **1e** and **2f**. This is confirmed in a higher value of the trigonality index τ (0.62).

Considering the studied species it seems that stronger distortion between square pyramidal to trigonal bipyramidal is a function of the alkyl chain length at the tris-chelating moiety. However, some complexes described in the literature do not follow this trend (Table 4). Only minor differences in τ values have been observed between compounds with $R' =$ ethyl and

Table 4 Trigonality index of prepared '3 + 1' complexes **1e**, **2f**, **3g** compared to data of other '3 + 1' complexes in the literature



'3 + 1' complex	R	R′	τ	Reference
1e	See Scheme 1	CH_3	0.47	This report
2f	See Scheme 1	C_2H_5	0.59	This report
3g	See Scheme 1	C_3H_7	0.62	This report
—	SC_6H_5	H	0.61	16
—	SC_6H_4Cl-*p*	C_2H_5	0.65	13
—	SC_6H_4Cl-*p*	$C_2H_4N(C_2H_5)_2$	0.63	15
(*syn*)	$SC_6H_4OCH_3$-*p*	$C_2H_4N(C_2H_5)_2$	0.62	14
(*anti*)	$SC_6H_4OCH_3$-*p*	$C_2H_4N(C_2H_5)_2$	0.05	14

diethylaminoethyl. The non-sensitivity of the τ value is shown for a complex with $R' = H$ ($\tau = 0.61$),[16] that consequently is more distorted to a trigonal-bipyramidal structure.

Unlike the "*syn*" oriented compounds, the τ value of the "*anti*" isomer tends to that of an ideal square-pyramidal arrangement even if R′ = diethylaminoethyl.[14] Thus, the distortion from square pyramidal to trigonal bipyramidal geometry observed is more distinct for the "*syn*" (SN(R′)S) species than for "*anti*" oriented complexes or (SSS) and (SOS) tridentate derived compounds described earlier.[17] These findings might be of interest with respect to *in vivo* and *in vitro* behavior since differences in the solvate shells are likely between the square-pyramidal and the trigonal bipyramidal arrangement of "*syn*" oriented compounds as described here.

Conclusion

New lipophilic '3 + 1' mixed-ligand rhenium(V) complexes bearing tertiary amino groups are easily prepared starting from *trans*-trichloromonooxo-bis(triphenylphosphine)rhenium(V). The formation of *cis*-dioxorhenium(V) complexes as by-products can be suppressed by strictly employing a 1 : 1 : 1 molar ratio of the reactants and a brief drying of the rhenium(V) precursor.

IR absorptions between 940 and 960 cm^{-1} are observed for the Re=O stretching vibration and mass spectrometry data confirm the proposed composition of the '3 + 1' complexes. X-Ray structural measurements of the representative complexes **1e**, **2f** and **3g** with "*syn*" arrangement of R′ with respect to the R=O group show a high degree of distortion in geometry from square pyramidal to trigonal bipyramidal (**1e** < **2f** < **3g**). Hence the co-ordination geometry seems to be related to the alkyl chain length R′ for such '3 + 1' [ReO(SN(R′)S)(SR)] complexes as described above. Thus an influence of the tridentate ligand in the '3 + 1' geometry and related parameters such as lipophilicity, hydrogen-bonding capacity, and co-ordination of solvent molecules is likely and has to be taken into consideration for the development of *in vivo* pharmaceuticals. The resulting non-radioactive complexes give a valuable basis for potential rhenium based radio-therapeutics and are useful as defined reference substances for HPLC identification of analogous ^{99m}Tc-technetium radiodiagnostics.

Experimental

General procedures

Ammonium perrhenate was obtained from Aldrich. Amino alkanethiols 2-dimethyl- and 2-diethyl-aminoethanethiol (**a**, **b**) were purchased from Fluka. The other applied ligands **c**, **d**, **e**, **f**, **g**, as well as the tris-chelating ligands $HSCH_2CH_2N(R')CH_2CH_2SH$ (R′ = Pr or Bu) were prepared in variation according to the literature,[18] whereas those where R′ = Me or Et were synthesized as described by Harley-Mason.[19] Silica gel 60 (70–230 mesh), obtained from Merck, was used for column chromatography of rhenium(V) complexes. Chloroform and methanol used for chromatography were of analytical grade.

UV/VIS spectra were recorded on a Specord M80 from Carl Zeiss, infrared spectra (KBr pellets) on a FT-IR-SPECTRUM 2000 spectrophotometer from Perkin-Elmer and mass spectra on a Finnigan MAT 95 mass spectrometer. Elemental analyses were performed on a Leco CHNS-932 elemental analyzer.

Preparations

***trans*-Trichloromonooxo-bis(triphenylphosphine)rhenium(V) [$ReOCl_3(PPh_3)_2$] P.** Triphenylphosphine (8.0 g, 30 mmol) was heated to 90 °C in glacial acidic acid (150 ml), in order to give a clear solution. Ammonium perrhenate (0.50 g, 1.85 mmol) was dissolved in 16 ml of concentrated hydrochloric acid and added dropwise over 10 minutes. The mixture was allowed to stay at 90 °C overnight. The resulting precipitate was separated by filtration, washed with 3 × 20 ml of acetic acid and with 3 × 20 ml of diethyl ether. The product was obtained quantitatively as a green-yellow solid. Yield 3.07 g, 99% (Found: C, 55.9; H, 4.0; Cl, 13.9. $C_{36}H_{30}Cl_3ORe$ requires: C, 56.1; H, 4.0; Cl, 13.8%. IR (KBr): 980 cm^{-1} (ν_{ReO}).[20]

[ReO(SN(R′)S)(SR)] 1a–4e (General procedure). To a stirred suspension of complex **P** (166 mg; 0.2 mmol) in a 0.15 M methanolic solution of sodium acetate (10 ml), a mixture of the SNS ligand (0.2 mmol) and the monodentate ligand (0.2 mmol) in methanol (2 ml) was added. The suspension was stirred and heated to 70 °C for approximately 40 minutes at which time the greenish yellow starting metal compound had been changed to dark green-brown. After cooling to room temperature, the reaction mixture was diluted with dichloromethane and aqueous hydrochloric acid (pH 4) was added. The aqueous phase was separated and 2 ml of dichloromethane were added. The pH was adjusted to 10 by adding sodium hydroxide. The organic layer was isolated, dried over sodium sulfate and evaporated to a final volume of 1 ml. The product was purified by liquid chromatography on silica gel eluting with trichloromethane and then trichloromethane–methanol (19 : 1) to yield the pure green product as determined by TLC. The complexes were isolated as green solids by complete removal of the solvent. After treating the green solid with diethyl ether, the residue was dissolved in dichloromethane (1 ml). X-Ray quality crystals were obtained from these solutions by adding 1 ml of methanol containing 2 drops of water followed by slow evaporation.

Crystal structure determination

Reflections were collected on an Enraf-Nonius CAD-4 diffractometer using graphite-monochromated Mo-Kα radiation for complex **1e** and Cu-Kα radiation for **2f** and **3g**. The structures were solved by Patterson methods (SHELXS 86). Non-hydrogen atoms were located from successive Fourier difference maps, and hydrogen atoms were calculated at idealized positions using a riding model. Final refinement was done by full-matrix least squares on F^2. For programs used and sources of scattering factor data see refs. 21 and 22. Crystal data are symmarized in Table 5.

CCDC reference number 186/2005.

See http://www.rsc.org/suppdata/dt/b0/b001600o/ for crystallographic files in .cif format.

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Table 5 Crystallographic data of complexes **1e**, **2f**, and **3g**

	1e	**2f**	**3g**
Molecular formula	$C_{11}H_{23}N_2O_2ReS_3$	$C_{15}H_{29}N_2O_3ReS_3$	$C_{14}H_{27}N_2O_2ReS_3$
Molecular mass	497.69	567.78	537.76
Space group	$P2_1/n$	$P2_1/n$	$P2_1/a$
Symmetry	Monoclinic	Monoclinic	Monoclinic
a/Å	11.767(3)	14.758(3)	12.630(4)
b/Å	11.422(9)	10.064(10)	12.017(2)
c/Å	13.299(6)	14.860(7)	14.817(4)
β/°	111.11(4)	118.32(2)	114.680(10)
V/Å^3	1668(2)	1942.9(10)	2043.4(9)
Z	4	4	4
T/K	296(2)	178(2)	298(2)
μ/mm^{-1}	7.662	15.386	6.260
Reflections			
unique	3441	3987	4900
observed [$I > 2\sigma(I)$]	3279	3851	3959
$R1$ (observed)	0.0545	0.0457	0.0695
$wR2$ (observed)	0.1442	0.1247	0.1714
R	0.0243	0.0296	0.0250

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