

CHELATE COMPOUNDS

Technical Field of the Invention

The invention relates to chelate compounds and their use as contrast agents in magnetic resonance imaging (MRI) procedures.

5 **Description of Related Art**

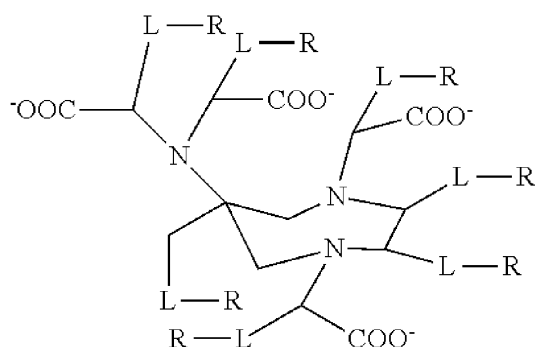
- MRI is a medical imaging technique in which areas of the body are visualised *via* the nuclei of selected atoms, especially hydrogen nuclei. The MRI signal depends upon the environment surrounding the visualised nuclei and their longitudinal and transverse relaxation times, T1 and T2. Thus, in the case
- 10 when the visualised nucleus is a proton, the MRI signal intensity will depend upon factors such as proton density and the chemical environment of the protons. Contrast agents can be used in MRI to improve the imaging contrast. They work by effecting the T1, T2 and/or T2* relaxation time and thereby influence the contrast in the images.
- 15 It is known that the T1, T2 and/or T2* relaxation times can be optimized for a chelated paramagnetic contrast agents by structural modification. Of particular importance is the presence and residence time of a water molecule bound to the paramagnetic ion and the rotational correlation time of the contrast agent. The presence and residence time of a water molecule, bound to the
- 20 paramagnetic ion, can be modulated by the choice of paramagnetic ion and the chelating moiety. The rotational correlation time can be modulated by varying the size of the contrast agent.

- Several types of contrast agents are known for use in MRI. Blood pool MR contrast agents, for instance superparamagnetic iron oxide particles, are
- 25 retained within the vasculature for a prolonged time. They have proven extremely useful to enhance contrast e.g. in the liver but also to detect capillary permeability abnormalities such as "leaky" capillary walls in tumours which are a result of tumour angiogenesis.

- The solubility of the paramagnetic chelate in water is also an important factor
- 30 when they are used as contrast agents for MRI because they are administered to patients in relatively large doses. A highly water-soluble paramagnetic

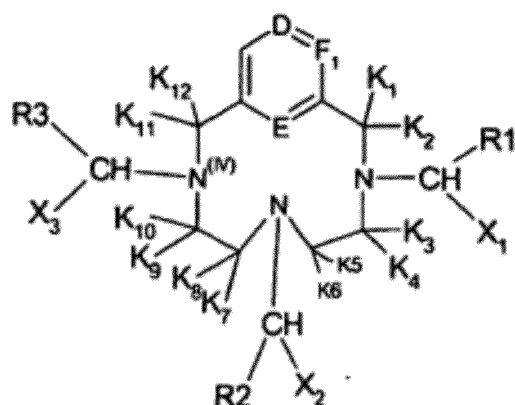
chelate requires a lower injection volume, is thus easier to administer to a patient and causes less discomfort. Water-soluble paramagnetic chelates, i.e. complexes of a chelator and a paramagnetic metal ion are well known – for instance the commercially-available gadolinium chelates Omniscan™ (GE Healthcare), Dotarem™ (Guerbet), Gadavist™ (Bayer) and Magnevist™ (Bayer). Because of their low molecular weight they rapidly distribute into the extracellular space (i.e. the blood and the interstitium) when administered into the vasculature. They are also cleared relatively rapidly from the body.

Several publications describe work carried out with the goal of developing improved paramagnetic chelate compounds. For example, US8540966 teaches the following generalised structure:

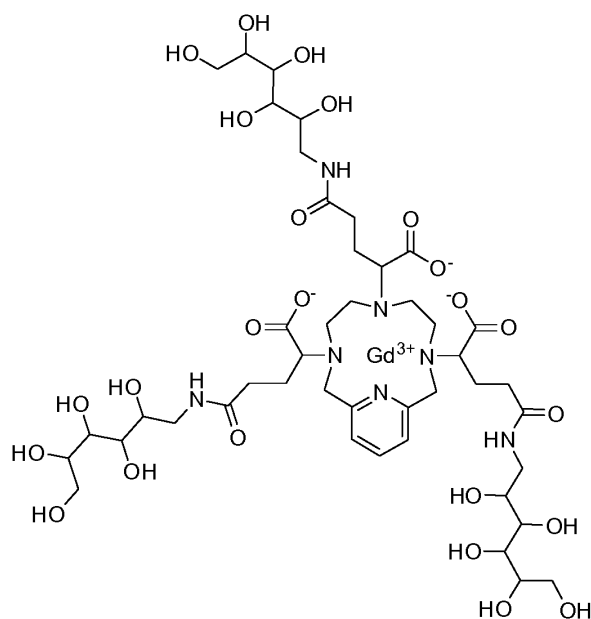


Where L is a linker and R is H or a C₂₋₇₀ aminopolyol moiety. The experimental examples of US8540966 compare certain of these compounds with commercially-available gadolinium chelates to demonstrate a similar pharmacokinetic profile but with higher relaxivity.

EP1931673 teaches the following generalised structure:



- Each R in the above structure is defined in EP1931673 as a co-ordinating ligand and each X comprises at least one C₁₋₆ hydroxyalkyl group. EP1931673 emphasises the relaxivity properties of the compounds. EP1931673 notes that
- 5 the compounds may be complexed with a paramagnetic metal ion selected from Gd³⁺, Mn²⁺ and Fe³⁺ but in reality the focus is on chelate structures that are suitable for stable complexation of Gd³⁺ e.g. the following gadolinium-containing complex:



- 10 All disclosed complexes are heptadentate, as four nitrogens and three carboxylic acid groups are coordinating to the complexed metal ion. The

detrimental effect of heptadentate manganese chelates has been described in WO2011073371.

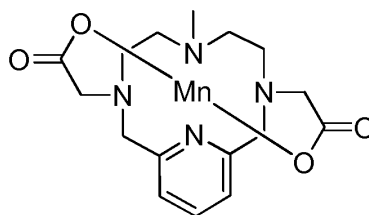
A key property of MRI chelate compounds is for the paramagnetic ion to be retained as far as possible within the chelate structure. Paramagnetic ion released from the chelate *in vivo* can interfere with biological pathways and potentially induce toxicity. The ability of a chelate to retain the paramagnetic ion (also referred to herein as stability) is also a property that can be modulated by structural design of the chelate moiety. Of particular interest is the kinetic stability, measured as a dissociation half-life, which indicates the degree of inertia towards altered chemical surroundings (i.e. endogenous ions). The above-cited publications do not discuss transmetallation inertness of the compounds they describe.

As can be appreciated from the commercially-available agents and the focus of the prior art, gadolinium is the most widely used paramagnetic metal ion for MRI chelates, which is down to its favourable relaxivity properties. Stability of the paramagnetic ion within the chelate structure is particularly important for gadolinium chelates as there are well-known issues connected with free gadolinium and toxicity. Because of these issues, there is a motivation to seek alternatives to gadolinium.

The manganese(II) ion is a paramagnetic species with a high spin number and a long electronic relaxation time and the potential of a manganese(II) based high relaxivity contrast agent has been reported in the literature (Tóth, É; Advances in Inorganic Chemistry, 2009, 61(09), 63–129). Certain manganese(II) chelates developed to date have however proved to be much less stable compared to corresponding gadolinium chelates. For example, the manganese chelate of DOTA (MnDOTA) is several hundred times less stable compared to the corresponding gadolinium complex (GdDOTA (Drahoš, B; Inorganic Chemistry, 2012(12), 1975–1986).

The work described in WO2011073371 demonstrates a molecular design that favours high chelate stability and a high relaxivity. This makes these compounds very suitable for use as MRI contrast agents. An exemplary compound of WO2011073371 has the following structure (also referred to

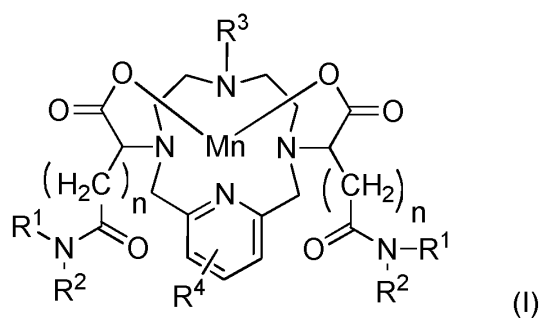
herein as “prior art Mn Chelate”):



Nevertheless, there is still scope for further manganese chelate compounds having improved and sustained kinetic stability while maintaining viable relaxation properties.

Summary of the Invention

In one aspect the present invention provides a compound of Formula I:



or a salt or solvate thereof, wherein:

each R^1 is independently selected from the group comprising C_{1-20} hydroxyalkyl, C_{1-6} alkyl, C_{3-6} aryl optionally-substituted with one or more substituents selected from halo and $-C(=O)-NH-C_{1-6}$ hydroxyalkyl, or a carbohydrate moiety;

each R^2 is independently selected from the group comprising C_{1-20} hydroxyalkyl, C_{1-6} alkyl or hydrogen;

R^3 is selected from the group comprising C_{1-3} alkyl or $-(CH_2)_m-C(=O)-NR^5R^6$ wherein m is an integer from 2-5, and R^5 and R^6 are as respectively defined for R^1 and R^2 ;

R^4 represents 0-3 substituents selected from the group comprising

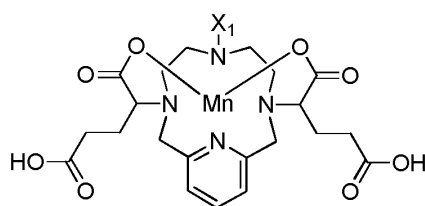
hydroxy, C₁₋₆ alkyl and C₁₋₆ hydroxyalkyl; and,

each n is an integer from 0-4;

and wherein the compound of Formula I comprises at least two hydroxy groups.

- 5 In another aspect, the present invention provides a method for the preparation of a compound of Formula I of the invention comprising:

(i) activating the carboxylate groups of a compound of Formula II with a peptide reagent

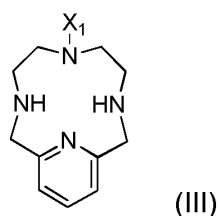


(II); then,

- 10 (ii) coupling said activated compound of Formula II with an amine derivative of substituent -NR¹R² to arrive at said compound of Formula I wherein R¹ and R² are as defined in Claim 1.

In another aspect, the present invention provides a method for the preparation of a compound of Formula II as defined herein comprising alkylation of a

- 15 compound of Formula III:



(III)

wherein X₁ is methyl or -(CH₂)₃-COOH.

In another aspect, the present invention provides a pharmaceutical composition comprising the compound of Formula I of the invention together with a

- 20 biocompatible carrier in a form suitable for mammalian administration.

In another aspect, the present invention provides a method comprising:

(i) administration to a subject of the compound of Formula I of the

invention or the pharmaceutical composition of the invention;

(ii) detection of magnetic resonance (MR) signals from said subject or parts of said subject in which said compound has distributed;

5 (iii) generation of MR images and/or MR spectra from said detected signals.

The compounds of the present invention have been demonstrated to possess properties that indicate their usefulness as MRI contrast agents.

The solubility of compounds of the invention measured as described in Example 13 demonstrated their suitability for use as contrast agents for MRI.

10 *In vitro* relaxivity measurements to evaluate the efficiency of compounds of the invention (see Example 14) demonstrated that these compounds induce an increase of both the longitudinal and transverse relaxation rates (e.g., $1/T_1$ and $1/T_2$ respectively) of the water molecules coordinated with the metal ion.

Experiments to test the kinetic inertness of compounds of the invention was
15 evaluated in the presence of competing metal ions Cu^{2+} and Zn^{2+} in slightly acidic solution (see Example 15). These experiments demonstrated that compounds of the present invention have favourable characteristics compared with the prior art.

Compounds of the invention showed an improvement in the kinetic inertness of
20 the Mn(II) based chelates with a slower dissociation compared to a prior art compound.

In summary therefore, the compounds of the present invention demonstrate an advantageous balance between contrast agent efficiency and improved stability
25 *in vivo* not previously demonstrated Mn(II) chelate compounds. The additional *in vivo* stability indicates that the compounds of the invention could be an attractive alternative to Gd(III) in the future generation of clinical contrast agents for medical MRI.

Brief Description of the Figures

30 Figure 1 illustrates the dissociation kinetics of Mn(II) based chelates as tested

in the methods of Example 15.

Figures 2 and 3 show ^1H NMRD profiles recorded for Mn(II) based chelates as measured by the method described in Example 14.

Figures 4 and 5 illustrate the results of the transmetallation experiments carried out for a prior art Mn chelate compound as described in Example 15.

Figures 6 and 7 shows a comparison of the transmetallation results obtained for a prior art compound and for certain compounds of the invention as described in Example 15.

Figure 8 shows the time dependent curve of the longitudinal relaxation time (i.e., T_1) for a compound of the invention.

Figures 9 and 10 illustrate the conversion caused by competing Cu^{2+} with Mn chelate compounds of the invention compared with a prior art Mn chelate compound.

Figure 11 illustrates the results obtained for a transmetallation reaction with Zn^{2+} with a prior art Mn chelate compared with a compound of the invention.

Detailed Description of the Preferred Embodiments

To more clearly and concisely describe and point out the subject matter of the claimed invention, definitions and exemplary embodiments are provided hereinbelow for specific terms used throughout the present specification and claims. Any exemplification of specific terms herein should be considered as a non-limiting example.

The terms “comprising” or “comprises” have their conventional meaning throughout this application and imply that the agent or composition must have the essential features or components listed, but that others may be present in addition. The term ‘comprising’ includes as a preferred subset “consisting essentially of” which means that the composition has the components listed without other features or components being present.

The term “alkyl”, alone or in combination, means a straight-chain or branched-chain alkyl radical having the general formula $\text{C}_n\text{H}_{2n+1}$. Examples of such

radicals include methyl, ethyl, and isopropyl.

The term “hydroxyl” refers to the group -OH.

The term “hydroxyalkyl” refers to an alkyl group as defined above comprising a hydroxyl substituent as defined above.

- 5 The term “aryl” refers to a functional group or substituent derived from an aromatic ring, usually an aromatic hydrocarbon, examples of which include phenyl and pyridyl. In one embodiment aryl groups of the present invention are aromatic 6-membered rings with between 0-3 heteroatoms selected from O, N and S.
- 10 The term “halogen” or “halo” means a substituent selected from fluorine, chlorine, bromine or iodine.

The term “carbohydrate moiety” refers to an aldehyde or a ketone derivative of a polyhydric alcohol and includes monosaccharide, disaccharide and oligosaccharide residues. Non-limiting examples include fructose, glucose and

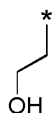
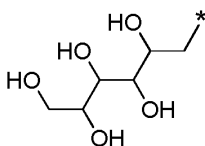
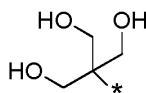
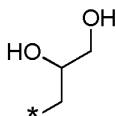
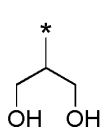
- 15 sucrose residues.

In one embodiment of said compound of Formula I each R¹ is C₁₋₁₂ hydroxyalkyl.

In one embodiment of said compound of Formula I each R¹ is C₃₋₆ hydroxyalkyl.

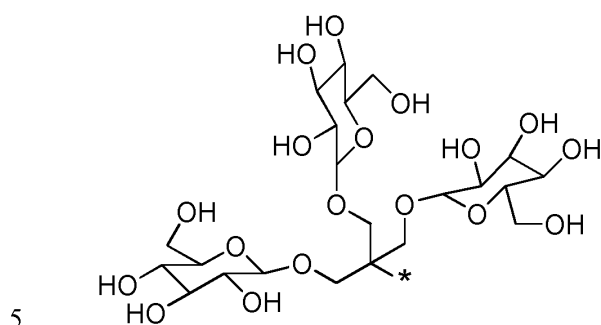
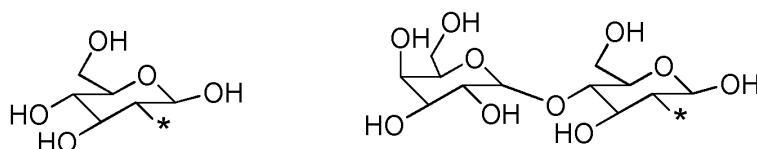
In one embodiment of said compound of Formula I each R¹ is C₆ hydroxyalkyl.

- 20 In one embodiment of said compound of Formula I each R¹ is independently selected from the group comprising:



wherein in each case the asterisk denotes the point of attachment to the rest of the compound of Formula I.

In one embodiment of said compound of Formula I each R¹ is independently selected from the group comprising:



wherein in each case the asterisk denotes the point of attachment to the rest of the compound of Formula I.

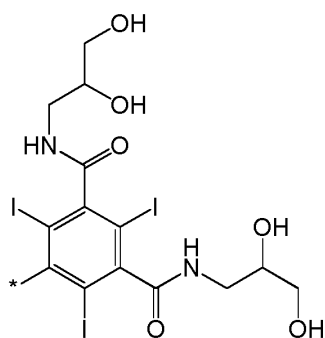
In one embodiment of said compound of Formula I each R¹ is a C₃₋₆ aryl substituted with one or more substituents selected from halo and -C(=O)-NH-C₁₋₆ hydroxyalkyl.

In one embodiment of said compound of Formula I said C₃₋₆ aryl is phenyl.

In one embodiment of said compound of Formula I said halo is iodo.

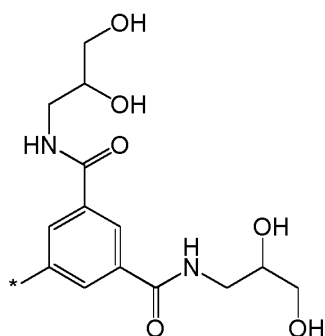
In one embodiment of said compound of Formula I -C(=O)-NH-C₁₋₆ hydroxyalkyl is -C(=O)-NH-CH₂-C(OH)-CH₂-C(OH).

15 In one embodiment of said compound of Formula I each R¹ is:



wherein the asterisk denotes the point of attachment to the rest of the compound of Formula I.

In one embodiment of said compound of Formula I each R¹ is:



5

wherein the asterisk denotes the point of attachment to the rest of the compound of Formula I.

In one embodiment of said compound of Formula I each R¹ is the same.

In one embodiment of said compound of Formula I each R² is C₁₋₃ alkyl.

10 In one embodiment of said compound of Formula I each R² is methyl.

In one embodiment of said compound of Formula I each R² is hydrogen.

In one embodiment of said compound of Formula I each R² is C₁₋₂₀ hydroxyalkyl.

In one embodiment of said compound of Formula I each R² is C₁₋₆ hydroxyalkyl.

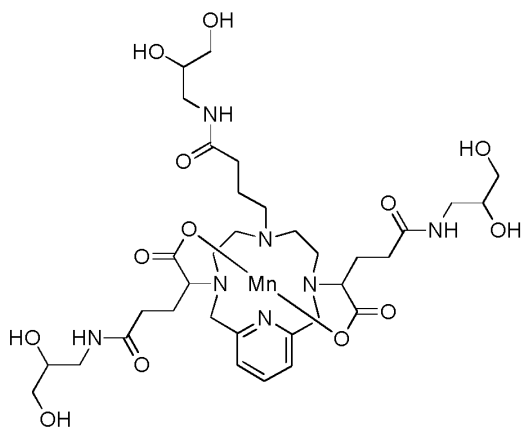
15 When each R² is C₁₋₆ hydroxyalkyl, in one embodiment each R¹ is also C₁₋₆ hydroxyalkyl, and in another embodiment R² and R¹ are the same.

In one embodiment of said compound of Formula I each R² is the same.

- In one embodiment of said compound of Formula I each n is an integer from 1-3.
- In one embodiment of said compound of Formula I n is 1.
- In one embodiment of said compound of Formula I n is 2.
- 5 In one embodiment of said compound of Formula I each n is 3.
- In one embodiment of said compound of Formula I R³ is C₁₋₃ alkyl.
- In one embodiment of said compound of Formula I R³ is methyl.
- In one embodiment of said compound of Formula I R³ is $-(CH_2)_m-C(=O)-NR^5R^6$ as defined herein.
- 10 In one embodiment of said compound of Formula I R⁵ is as defined for R¹ herein.
- In one embodiment of said compound of Formula I R⁶ is as defined for R² herein.
- In one embodiment of said compound of Formula I m is 3.
- 15 In one embodiment of said compound of Formula I n is 2.
- In one embodiment of said compound of Formula I R⁴ represents 0 substituents.
- In one embodiment of said compound of Formula I R⁴ represents 1 or 2 hydroxy groups.
- 20 In one embodiment of said compound of Formula I R⁴ represents 2 hydroxy groups at the meta positions of the pyridyl ring.
- In one embodiment said compound of Formula I comprises at least 4 hydroxy groups.
- In one embodiment said compound of Formula I comprises 4-15 hydroxy
- 25 groups.
- In one embodiment said compound of Formula I comprises 5-10 hydroxy groups.
- In one embodiment of the compound of the invention said Mn is an enriched

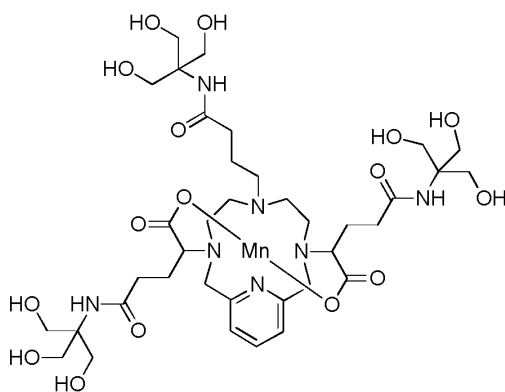
isotope of Mn selected from the group comprising ^{52}Mn and ^{54}Mn . In one embodiment said Mn isotope is ^{54}Mn .

Non-limiting examples of compounds of Formula I are the following compounds:

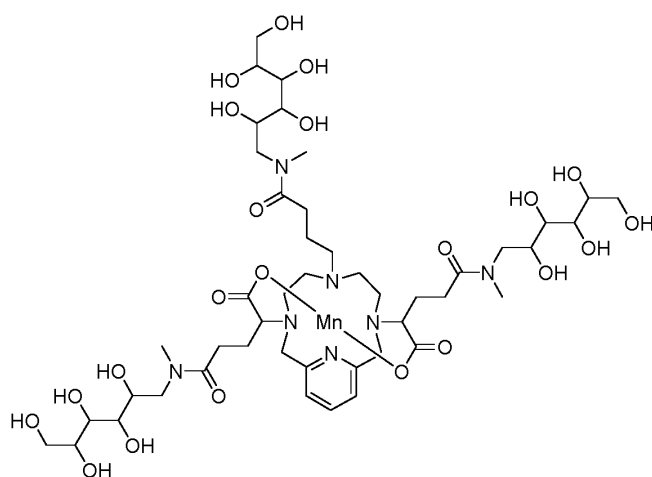


Mn Chelate 1 Racemate

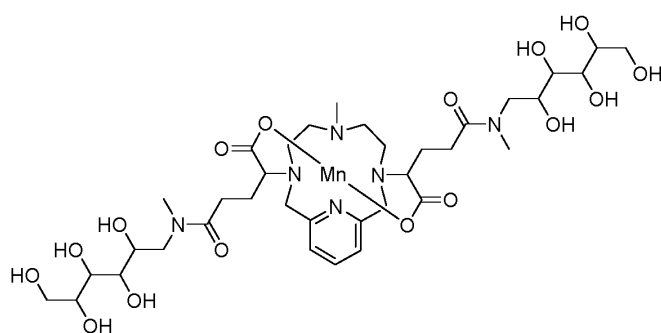
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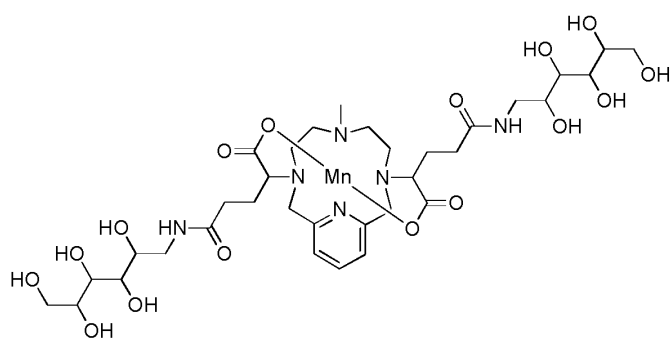
Mn Chelate 2 Racemate



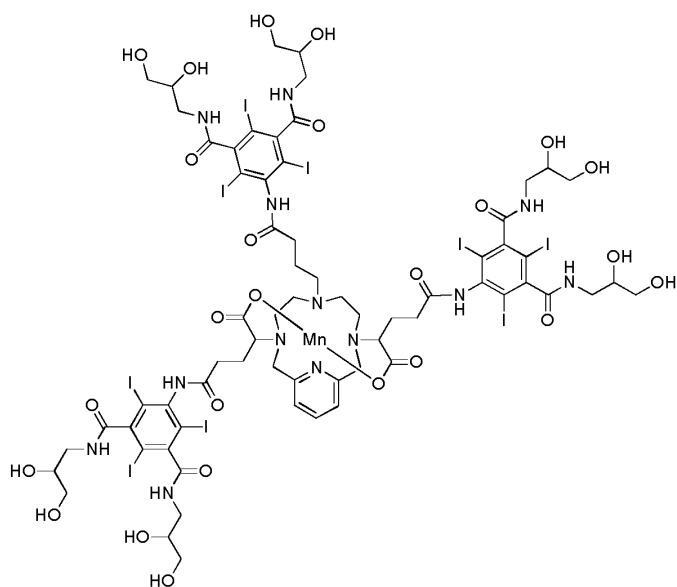
Mn Chelate 3 Racemate



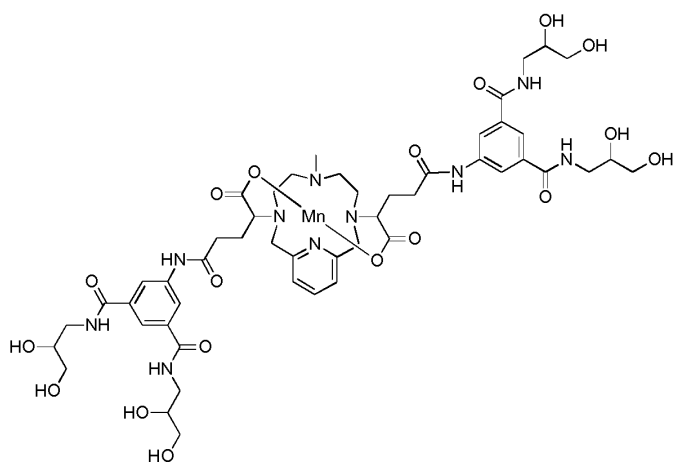
Mn Chelate 4 Racemate



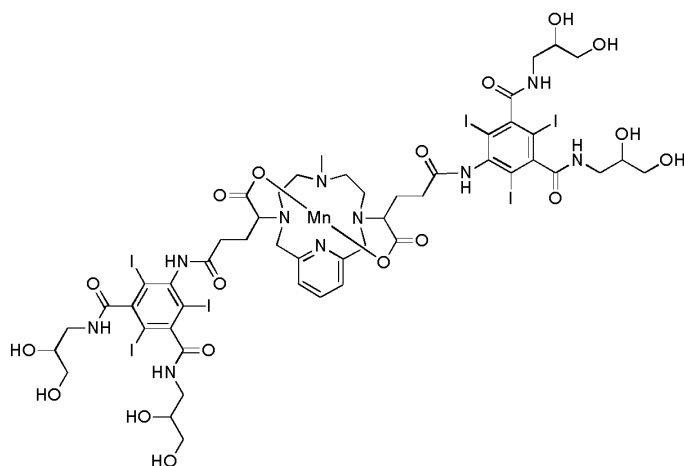
Mn Chelate 5 Racemate



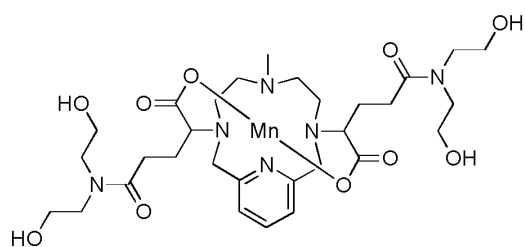
Mn Chelate 6 Racemate



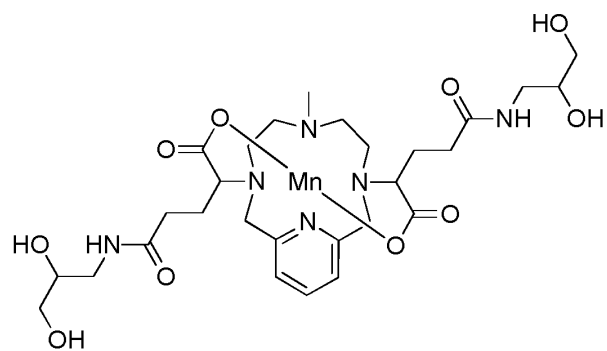
Mn Chelate 7 Racemate



Mn Chelate 8 Racemate

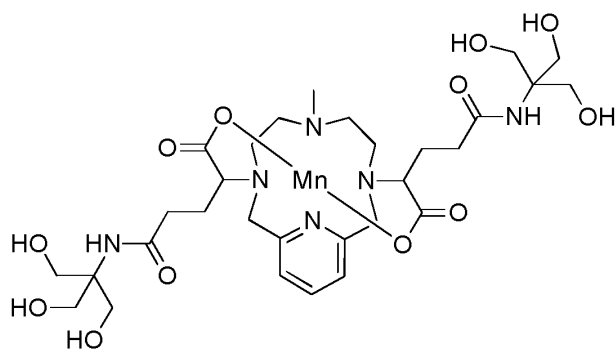


Mn Chelate 9 Racemate

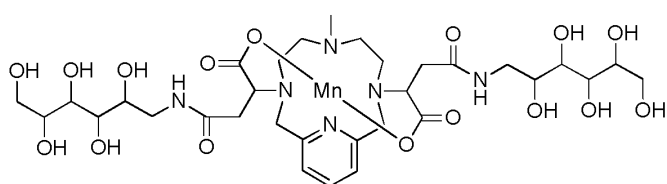


Mn Chelate 10 Racemate

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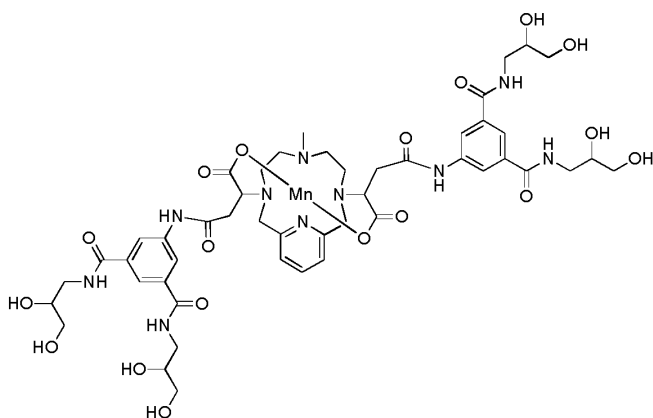


Mn Chelate 11 Racemate

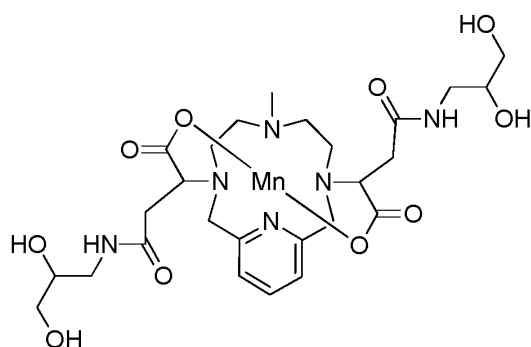


Mn Chelate 5a Racemate

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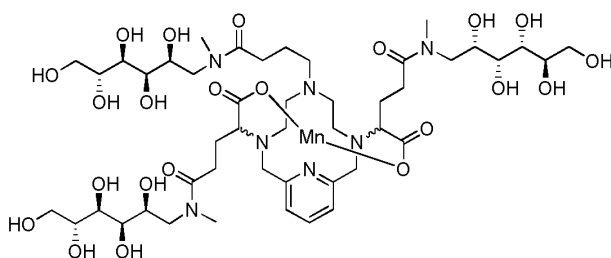


Mn Chelate 7a Racemate

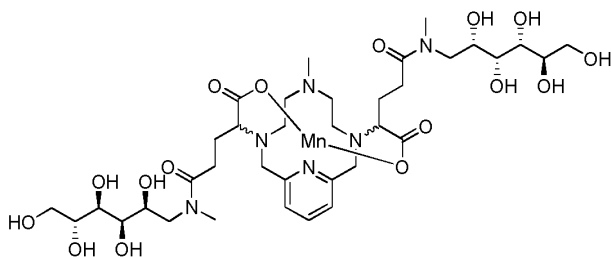


Mn Chelate 10a Racemate

- In the compounds of Formula I the carbons attached to the carboxylate arms are stereocentres. The compounds of Formula I of the invention may be provided as racemic mixture or as an enantiomerically-enriched mixture, or the racemic mixture may be separated using well-known techniques and an individual enantiomer maybe used alone. In one embodiment, the compound of Formula I is either a racemic mixture or diastereomerically pure. In one embodiment, the compound of Formula I is diastereomerically pure.
- 10 Non-limiting examples of diastereomerically pure compounds of Formula I are the following compounds:

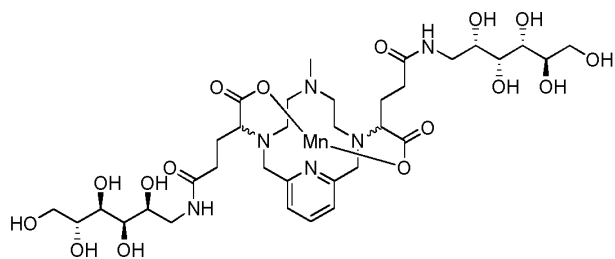


Mn Chelate 3



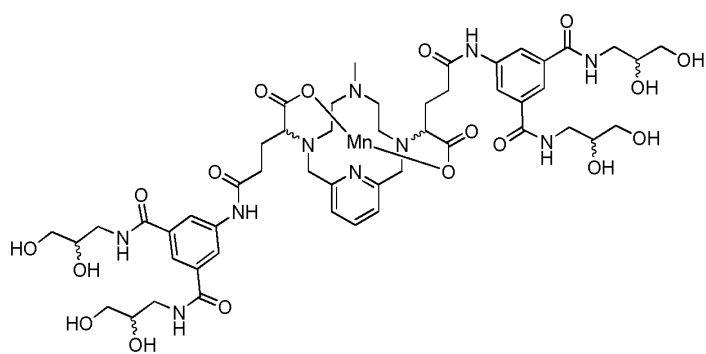
Mn Chelate 4

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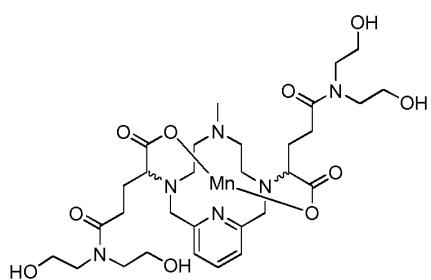


Mn Chelate 5

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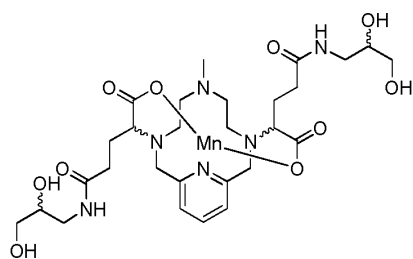


Mn Chelate 7

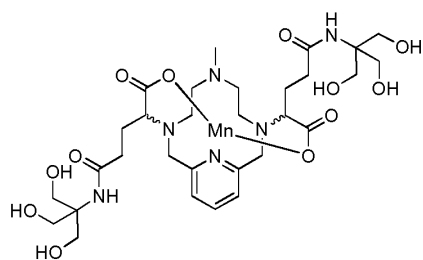


Mn Chelate 9

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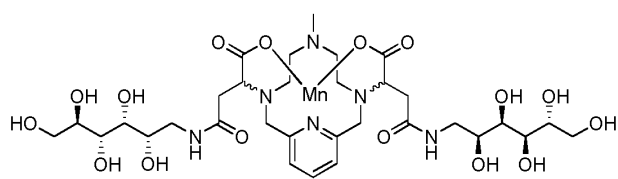


Mn Chelate 10

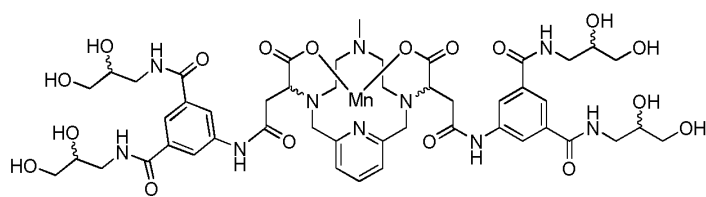


Mn Chelate 11

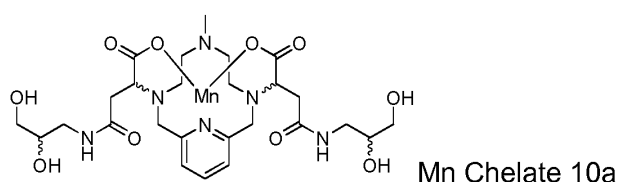
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Mn Chelate 5a



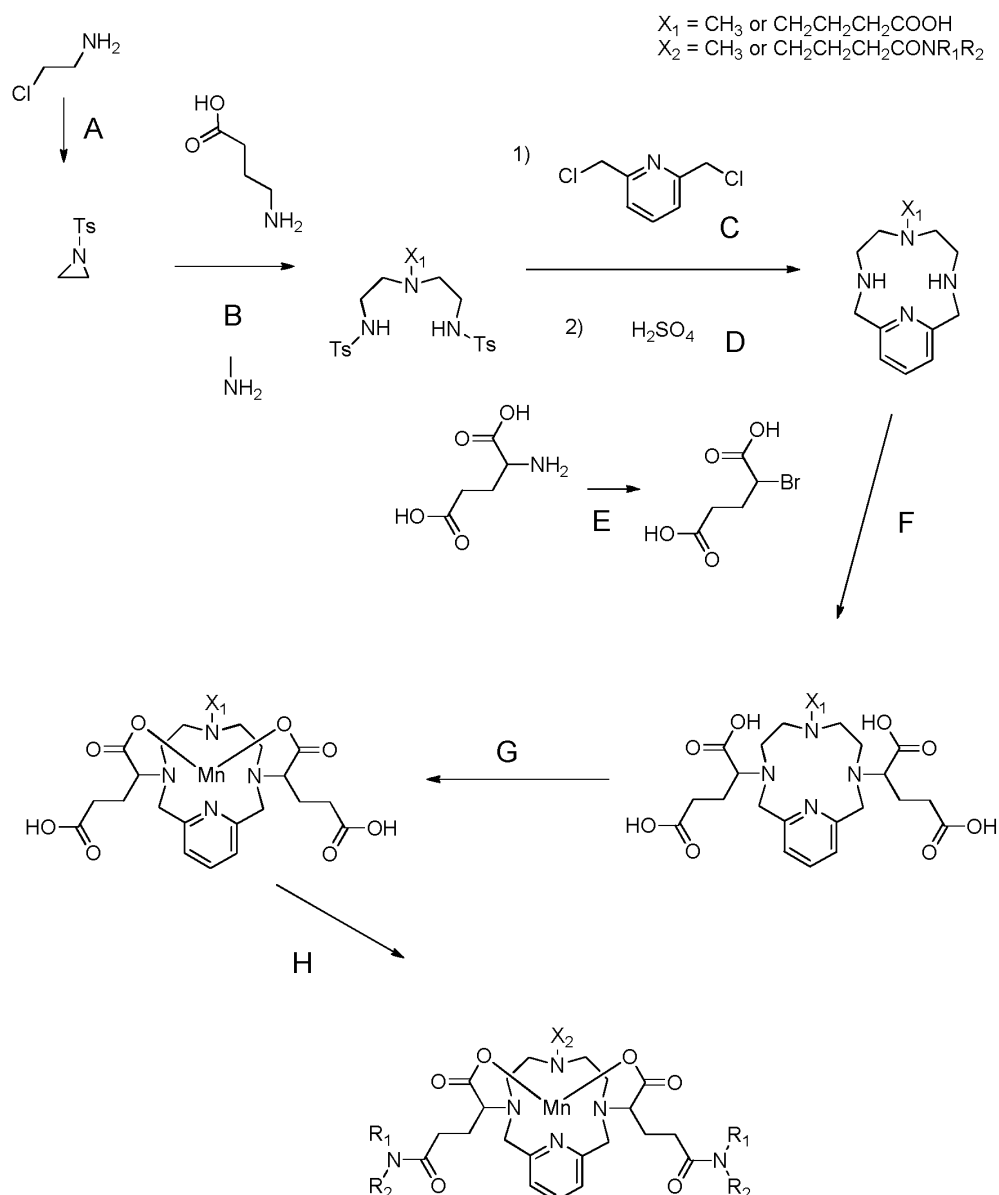
Mn Chelate 7a



Hydrophilic derivatization to obtain the compounds of the invention is achieved via an amide bond to an aliphatic linker. The amide, which is a non-coordinating attachment group, is too distant from the manganese ion and therefore will not coordinate. The exact length of the non-coordinating linker at R³ of Formula I is very important, if too short (i.e. if m=1 in Formula I) there is risk for the amide group coordinating to the manganese ion, thus blocking access of water molecule, dramatically reducing the overall relaxivity of the complex. The length of the non-coordinating linker attached to a carboxymethyl arm (coordinating group) can be short (i.e. where n=0 in Formula I) as the same “arm” is unable to facilitate two coordinating groups (coordination angle will be too strained).

The compounds of Formula I can be synthesized by several synthetic pathways known to the skilled artisan from commercially available starting materials.

Suitable sources of manganese for incorporation into a chelate when making compounds of the present invention include salts of carbonate (MnCO₃), oxide (MnO), acetate (Mn(OAc)₂), chloride (MnCl₂), hydroxide (Mn(OH)₂), oxalate (MnC₂O₄), formate (Mn(HCO₂)₂) and nitrate (Mn(NO₃)₂). The following generalized procedure may be used and/or readily adapted to obtain compounds of Formula I:



In summary:

A: Tosylation of aminoethanol gives aziridine (Carrillo, Arkivoc, 2007).

B: Aziridation of aminobutanoic acid (Sigma Aldrich catalogue 56-12-2). In one embodiment aziridination of methylamine proceeds in neat acetonitrile). In one embodiment for this amino acid some base is used to activate amine.

C: Cyclization with 2,6-bis(chloromethyl)-Pyridine (Sigma Aldrich catalogue

3099-28-3). In one embodiment, this step is carried out in acetonitrile with potassium carbonate as the base.

D: De-tosylation using in one embodiment concentrated sulphuric acid. In one embodiment, this step proceeds quantitatively.

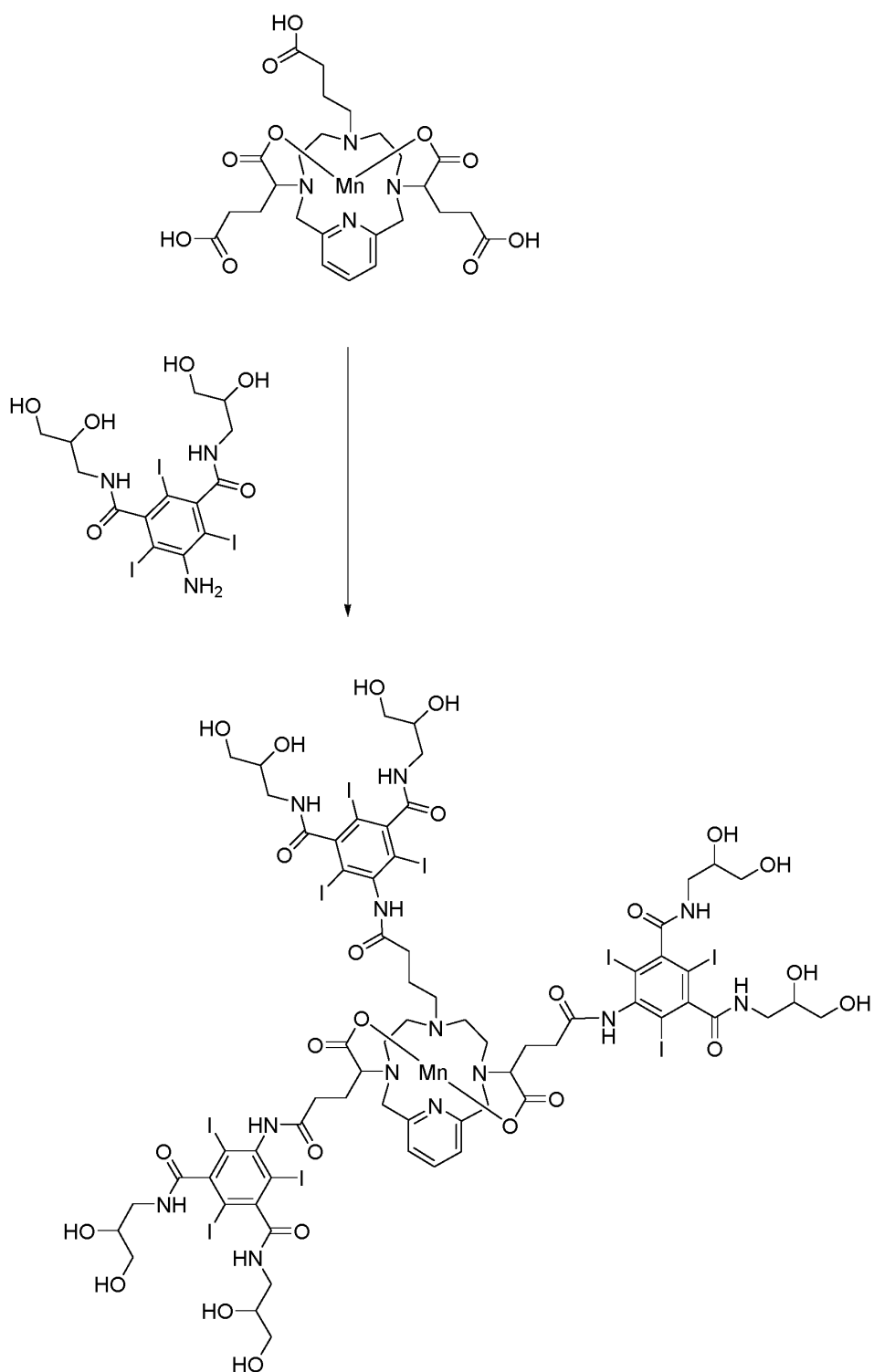
- 5 **E:** Bromination based on method described in literature (Henig, J., Tóth, É., Engelmann, J., Gottschalk, S., & Mayer, H. a. (2010). Inorganic Chemistry, 49(13), 6124–38).

- F:** Alkylation of the polyamine. In one embodiment, this step is carried out in aqueous solution. In another embodiment, where secondary halides react
10 sluggishly (primary alkylhalides proceeds well) it is possible to synthesize bis-ester (E) and switch to organic solvent to improve reaction speed.

G: Complexation using MnCl_2 . Precipitate excess Mn using base.

- H:** Activate carboxylates with peptide reagents. In one embodiment, these reagents are EDCI and/or HOBT (as described in EP2457914 B1). Couple with
15 suitable amine (e.g. Meglumine).

Where the compound of Formula I comprises at R^1 a substituted aryl such as a triiodiated phenyl, the compounds may be obtained using or adapting the following reaction scheme:



A non-limiting selection of compounds of the invention were synthesised as

described below in Examples 1-10 and a compound of the prior art was synthesised as described in Example 11. These compounds were characterised *in vitro* and/or *in vivo* as described in Examples 12-15.

Suitable methods for *in vitro* characterization of chelate stability can be found in the literature (Idée, J.-M. Journal of Magnetic Resonance Imaging: JMRI, 2009, 30(6), 1249–58 and Baranyai, Z. Chemistry - A European Journal, 2015, 21(12), 4789–4799). Other suitable methods include *in vitro* studies of physiological media (i.e. human serum or plasma) to monitor the transmetallation inertness. Another suitable method of assessing transmetallation inertness would be to measure retention of metal ions *in vivo*, following injection of the chelated metal. It is known that intact chelates normally follows very rapid clearance kinetics.

In one aspect of the invention the compound of Formula I is provided as a pharmaceutical composition.

A “pharmaceutical composition” is a composition comprising the compound of the invention, together with a biocompatible carrier in a form suitable for mammalian administration. The “biocompatible carrier” is a fluid, especially a liquid, in which the compound of Formula I is suspended or dissolved, such that the resulting composition is physiologically tolerable, i.e. can be administered to the mammalian body without toxicity or undue discomfort (which can be understood to be a definition of the term “suitable for mammalian administration”).

The pharmaceutical composition of the invention is suitable for use as a magnetic resonance (MR) contrast medium in magnetic resonance imaging (MRI) of the human and non-human animal body.

In one embodiment, the pharmaceutical composition of the invention may comprise one or more pharmaceutically-acceptable excipients. These suitably do not interfere with the manufacture, storage or use of the final composition.

Non-limiting examples of suitable pharmaceutically-acceptable excipients include buffering agents, stabilizers, antioxidants, osmolality adjusting agents, pH adjusting agents, excess cheland and weak complexes of physiologically

tolerable ions. These and other suitable excipients will be well known to those of skill in the art and are further described in e.g. WO1990003804, EP0463644-A, EP0258616-A and US5876695 the content of which are incorporated herein by reference. The pharmaceutical composition of the invention in one
5 embodiment is in a form suitable for parenteral administration, for example injection. The pharmaceutical composition according to the invention may therefore be formulated for administration using physiologically acceptable excipients in a manner fully within the skill of the art. For example, the compound of Formula I, optionally with the addition of pharmaceutically
10 acceptable excipients, may be suspended or dissolved in an aqueous medium, with the resulting solution or suspension then being sterilized.

A non-limiting example of a suitable buffering agent is tromethamine hydrochloride.

The term "excess cheland" is defined as any compound capable of scavenging
15 free paramagnetic ion (manganese), but not paramagnetic ion (manganese) retained within the complexes of this invention, as described in EP2988756A1. Although small amounts are essential to human health, overexposure to free manganese ions may result in the neurodegenerative disorder known as "manganism" with symptoms resembling Parkinson's disease. However, the
20 fundamental issue for Mn, as well as other metals, as contrast agents is in their chelation stability. Chelation stability is an important property that reflects the potential release of free metal ions *in vivo*. It is known that there is a correlation between the amount of excess cheland in a paramagnetic chelate formulation and the amount of paramagnetic metal deposited in animal models (Sieber
25 2008 J Mag Res Imaging; 27(5): 955-62). Therefore, in another embodiment, an amount of excess cheland is selected that can act as a Mn scavenger to reduce or prevent release of Mn from the formulation post injection. The optimal amount of free cheland will result in a pharmaceutical composition having suitable physicochemical properties (i.e. viscosity, solubility and
30 osmolality) and avoiding toxological effects such as zinc depletion in the case of too much free cheland. US5876695 describes in particular an excess of linear chelate, in particular of free DTPA, and this is a non-limiting example of an

excess chelant suitable for use in the pharmaceutical composition of the present invention. This formulation strategy is used for products such as Magnevist™, Vasovist™ or Primovist™. WO2009103744 describes a similar formulation strategy, based on the addition of a precise amount of free chelate, to have a very small excess of said chelate and a zero concentration of free lanthanide.

The physiologically tolerable ion may in one embodiment be selected from physiologically tolerable ions include calcium or sodium salts such as calcium chloride, calcium ascorbate, calcium gluconate or calcium lactate.

Parenterally administrable forms should be sterile and free from physiologically unacceptable agents and should have low osmolality to minimize irritation or other adverse effects upon administration and thus the pharmaceutical composition should be isotonic or slightly hypertonic. Non-limiting examples of suitable vehicles include aqueous vehicles customarily used for administering parenteral solutions such as Sodium Chloride Injection, Ringer's Injection, Dextrose Injection, Dextrose and Sodium Chloride Injection, Lactated Ringer's Injection and other solutions such as are described in Remington's Pharmaceutical Sciences, 22nd Edition (2006 Lippincott Williams & Wilkins) and The National Formulary (https://books.google.com/books?id=O3qixPEMwssC&q=THE+NATIONAL+FORMULARY&dq=THE+NATIONAL+FORMULARY&hl=en&sa=X&ved=0CC8Q6AEwAGoVChMImfPHrdTqyAIVJfNyCh1RJw_E).

For the pharmaceutical composition of the invention to be administered parenterally, i.e. by injection its preparation further comprises steps including removal of organic solvent, addition of a biocompatible buffer and any optional further ingredients such as excipients or buffers. For parenteral administration, steps to ensure that the pharmaceutical composition is sterile and apyrogenic also need to be taken.

In another embodiment, the present invention provides a method comprising administration of the compound of Formula I as defined herein in the generation of MR images and/or MR spectra.

- Methods of administration and subjects envisaged as suitable in the context of the present invention have been described hereinabove in connection with the pharmaceutical composition. Administration of the compound of Formula I is preferably carried out parenterally, and most preferably intravenously. The intravenous route represents the most efficient way to deliver the compound throughout the body of the subject. Furthermore, intravenous administration does not represent a substantial physical intervention or a substantial health risk. The compound of Formula I of the invention is preferably administered as the pharmaceutical composition of the invention, as defined above. The method of the invention can also be understood as comprising steps (ii)-(iii) carried out on a subject to whom the compound of the invention has been pre-administered. In one embodiment, the pharmaceutical composition is administered in an amount suitable to enhance the contrast in a method of MR imaging (MRI). For further detail on MRI methods the reader is referred to the common general knowledge in the art, e.g. as taught in Chapter 27 "Contrast Agents and Magnetic Resonance Imaging" in "Magnetic Resonance Imaging: Physical and Biological Principles" (4th Edition 2015 Elsevier, Stewart Carlyle Bushong & Geoffrey Clarke, Eds.) or in "Contrast Agents I: Magnetic Resonance Imaging" (2002 Springer-Verlag, Werner Krause, Ed.).
- The method of the invention may be used to study a biological marker or process in healthy subjects, or alternatively in subjects known or suspected to have a pathological condition associated with abnormal expression of a biological marker. When the method is used to image a subject known or suspected to have a pathological condition it has utility in a method for the diagnosis of said condition.
- The "detection" step of the method of the invention involves detection of signals emitted by the compound of Formula I by means of a detector sensitive to said signals. This detection step can also be understood as the acquisition of signal data.
- The "generation" step of the method of the invention is carried out by a computer which applies a reconstruction algorithm to the acquired signal data to yield a dataset. This dataset is then manipulated to generate one or more

images and/or one or more spectra showing the location and/or amount of signals.

The “subject” of the invention can be any human or animal subject. In one embodiment, the subject of the invention is a mammal. In one embodiment
5 said subject is an intact mammalian body *in vivo*. In another embodiment, the subject of the invention is a human.

This written description uses examples to disclose the invention, including the best mode, and to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any
10 incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial
15 differences from the literal languages of the claims. All patents and patent applications mentioned in the text are hereby incorporated by reference in their entireties, as if they were individually incorporated.

Brief Description of the Examples

- Example 1 describes the synthesis of Mn Chelate 3.
- 20 Example 2 describes the synthesis of Mn Chelate 4.
- Example 3 describes the synthesis of Mn Chelate 5.
- Example 4 describes the synthesis of Mn Chelate 7.
- Example 5 describes the synthesis of Mn Chelate 9.
- Example 6 describes the synthesis of Mn Chelate 10.
- 25 Example 7 describes the synthesis of Mn Chelate 11.
- Example 8 describes the synthesis of Mn Chelate 5a.
- Example 9 describes the synthesis of Mn Chelate 7a.
- Example 10 describes the synthesis of Mn Chelate 10a.
- Example 11 describes the synthesis of a prior art Mn Chelate.

Example 12 describes *in vivo* ^{54}Mn biodistribution studies in rats.

Example 13 describes characterisation of the water solubility of compounds of the invention.

Example 14 describes *in vitro* proton relaxivity and nuclear magnetic relaxation dispersion (NMRD) profiles of compounds of the invention.

Example 15 describes experiments carried out to determine the dissociation kinetics of compounds of the invention.

List of Abbreviations used in the Examples

10	AcN	acetonitrile
	DMSO	dimethylsulfoxide
	EDCI	1-ethyl-3-(3-dimethylaminopropyl)carbodiimide
	EtOAc	ethyl acetate
	EtOH	ethanol
15	h	hour(s)
	HOBt	hydroxybenzotriazole
	MeOH	methanol
	NMR	nuclear magnetic resonance
	NMRD	nuclear magnetic relaxation dispersion

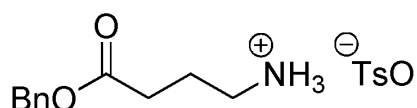
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Examples

Example 1: Synthesis of Mn Chelate 3

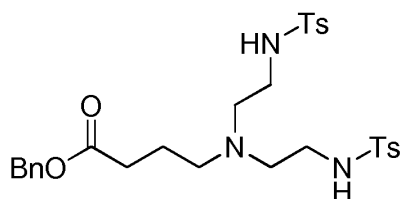
Example 1(i) : Synthesis of 4-(benzyloxy)-4-oxobutan-1-aminium 4-methylbenzenesulfonate

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A 2L 3-necked flask was fitted with a mechanical stirred, a Dean-Stark trap, reflux condenser, and a nitrogen inlet. The flask was charged with 4-aminobutanoic acid (41.522 g, 0.403 mol), *p*-toluenesulfonic acid (91.912 g, 0.048 mol), and benzyl alcohol (201 mL). The resulting cloudy solution was heated at reflux for 14 h. At the end of the reflux period, *n*-heptane (175 mL) was added to the hot reaction solution. The reaction was allowed to cool to ambient temperature. The resulting white crystals were isolated *via* vacuum filtration and recrystallized from 6:1 ethyl acetate/*n*-heptane to give 124.2 g (84% yield) of the desired product as a white solid. ¹H NMR (400 MHz, CDCl₃, δ) 7.71 (5H, d), 7.31 (5H, m), 7.13 (2H, d), 5.02 (2H, s), 2.87 (2H, m), 2.32 (5H, m), 1.85 (2H, m).

Example 1(ii): Synthesis of benzyl 4-(bis(2-(4-methylphenylsulfonamido)ethyl)amino)butanoate

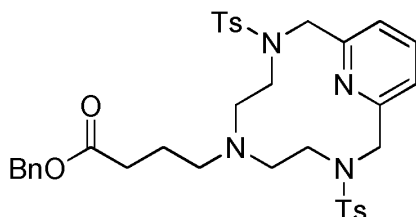


A 2L jacketed reactor fitted with a 4-blade anchor shaped stir paddle, a reflux condenser, and a nitrogen inlet was charged with *N*-tosylaziridine (107.7 g, 0.546 mol) and anhydrous acetonitrile (870 mL). 4-(Benzyloxy)-4-oxobutan-1-aminium 4-methylbenzenesulfonate (100 g, 0.274 mol) and anhydrous acetonitrile (500 mL) were then added to give an off white suspension. Diisopropylamine (47.6 mL, 0.274 mol) was added and the reaction was stirred at 40 °C for 16 h. The reaction was then cooled to 22.5 °C and stirred for an additional 49 h. The cloudy white suspension was vacuum filtered and the clear yellow filtrate was evaporated to dryness. The crude material was purified by silica gel chromatography (50% hexanes in EtOAc to 10% hexanes in

EtOAc; both eluents contained 1% triethylamine) to give 89.7 g (54%) of the desired product as a colourless oil. ¹H NMR (400 MHz, CD₂Cl₂, δ) 7.74 (4H, d), 7.35 (9H, m), 5.13 (2H, m), 5.10 (2H, s), 2.85 (4H, m), 2.41 (10H, m), 2.23 (4H, m), 1.60 (2H, m).

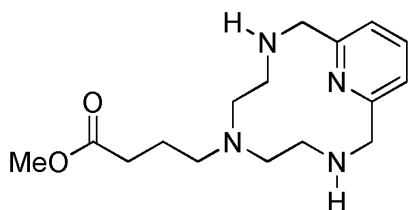
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Example 1(iii): Synthesis of protected cyclic 3-arm chelate



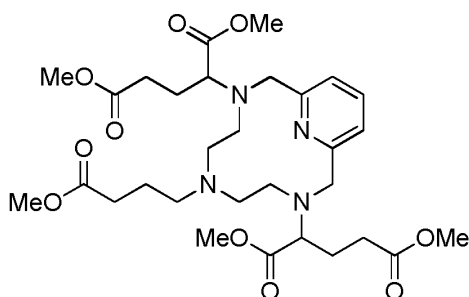
A 3L 3-necked round bottomed flask fitted with a mechanical stirrer, a reflux condenser, and a nitrogen inlet was charged with 8 6mm diameter glass balls, benzyl 4-(bis(2-(4-methylphenylsulfonamido)ethyl)amino)butanoate (143.9 g, 0.245 mol) and 2,6-Bis(chloromethyl)pyridine (43.1 g, 0.245 mmol). Anhydrous acetonitrile (1.632 L) was added followed by anhydrous potassium carbonate (135.5 g, 0.980 mol) and the resulting solution was heated at 80 °C for 47 h. The resulting suspension was then cooled to ambient temperature and stirred for an additional 65 h. Anhydrous potassium carbonate (67.0 g, 0.485 g) was added and the reaction was stirred at ambient temperature for 27 h. The insoluble potassium carbonate was removed *via* vacuum filtration and the clear orange filtrate was evaporated to dryness. The crude material was purified by silica gel chromatography (100% CH₂Cl₂ to 10% MeOH in CH₂Cl₂; both eluents contained 1% triethylamine) to give 70.9 g (42 %) of the desired product as a white foam. ¹H NMR (400 MHz, CD₂Cl₂, δ) 7.72 (5H, m), 7.34 (9H, m), 7.26 (2H, d), 5.09 (2H, s), 4.31 (4H, s), 3.07 (4H, m), 2.43 (6H, s), 2.28 (8H, m), 1.61 (2H, m).

Example 1(iv): Synthesis of deprotected 3-arm cyclic chelate



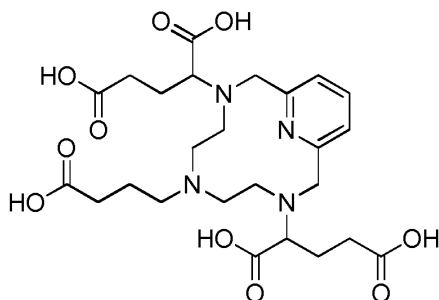
A 3L 3-necked round-bottomed flask fitted with a mechanical stirrer, a reflux condenser, and a stopper was charged with protected cyclic 3-arm chelate (70.5 g, 92.3 mmol) and concentrated H₂SO₄ (282 mL) and heated at 100 ° for 19 h. The resulting black solution was cooled to ambient temperature and the pH was adjusted to 7 with 50 wt% NaOH in water. MeOH (1 L) was added and the solids were removed *via* vacuum filtration. The filtrate was concentrated to dryness to leave a black residue which was triturated with MeOH (500 mL) at 60 °C for 1 h. The insoluble material was removed *via* vacuum filtration and the filtrate was concentrated to dryness. The resulting caramel coloured semisolid was dissolved in MeOH (1L) and the pH was adjusted to approximately 1 with concentrated H₂SO₄ and stirred at ambient temperature for 18 h. The solution was then heated to 60 °C with stirring for 25 h. The insoluble material was removed *via* vacuum filtration and the pH of the filtrate was adjusted to 7 with potassium carbonate. Undissolved potassium carbonate was removed *via* vacuum filtration and the filtrate was evaporated to dryness. The resulting off-white solid was triturated with anhydrous acetonitrile (1 L) and the insoluble material was removed *via* vacuum filtration. The filtrate was evaporated to dryness to give a 25.3 g (89.6%) of the desired product (ESI: m/z = 306 (M + H⁺)) as a white solid.

Example 1(v): Synthesis of protected Mn 3-arm C5 chelate



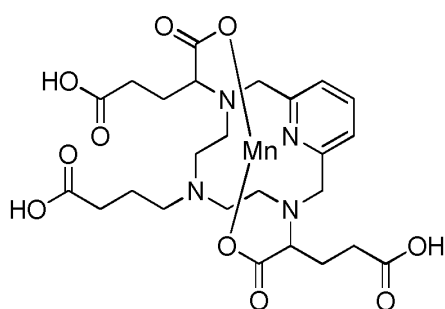
A 100 mL round bottomed flask fitted with a magnetic stir bar and a reflux condenser was charged with deprotected 3-arm cyclic chelate (2.776 g, 9.06 mmol) and anhydrous acetonitrile (60.4 mL). Triethylamine (3.16 mL, 22.7 mmol) was then added followed by dimethyl 2-bromopentanedioate (4.982 g, 20.8 mmol) and the resulting solution was heated at 65 °C for 20 h. A second aliquot of dimethyl 2-bromopentanedioate (1.36 g, 5.7 mmol) was added and heating was continued for an additional 23 h. The solvent was removed in vacuo and the crude material was purified on C₁₈ silica gel (30% acetonitrile in water) to give 2.883 g (51%) of the desired product (ESI: m/z = 623 (M + H⁺)) as a yellow oil.

Example 1(vi): Synthesis of deprotected Mn 3-arm C5 chelate



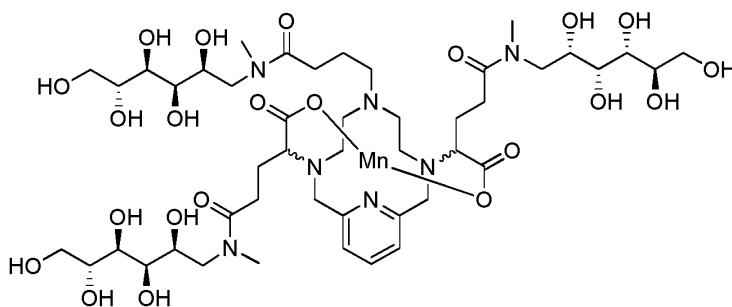
A 500 mL round bottomed flask fitted with a magnetic stir bar was charged with protected Mn 3-arm C5 chelate (14.010 g, 22.5 mmol) dissolved in water (225 mL) and 12.5 M NaOH (18.0 mL) was added. The resulting solution was stirred at ambient temperature for 18 h. The pH was then adjusted to 6 with conc. HCl and the solvent was removed in vacuo. The crude residue was purified on C₁₈ silica gel (100% water to 15% AcN in water) to give 12.43 g (100%) of the desired product (ESI: m/z = 553 (M + H⁺)) as a yellow oil.

Example 1(vii): Synthesis of Mn 3-arm C5 chelate



A 1L 3-necked round bottomed flask fitted with a magnetic stir bar was charged with deprotected Mn 3-arm C5 chelate (12.43 g, 22.5 mmol), manganese chloride tetrahydrate (8.90 g, 45.1 mmol) and water (405 mL). The resulting solution was stirred at ambient temperature for 12.5 h. The pH was then adjusted to 6 and the reaction was heated at 75 °C for 7 h. The solution was cooled to ambient temperature and the pH was adjusted to 8 with saturated aqueous sodium carbonate. The resulting white precipitate was removed *via* vacuum filtration and the filtrate was evaporated to dryness in vacuo. The crude residue was purified on C₁₈ silica gel (100% water) to give 13.33 g (98%) of the desired product (ESI: $m/z = 606 (M + H^+)$) as a yellow solid.

Example 1(viii): Synthesis of Mn Chelate 3

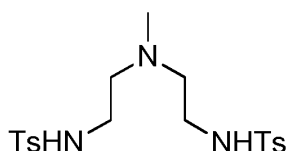


A 100 mL 3-necked flask fitted with a mag stir bar was charged with Mn 3- arm C5 chelate (1.54 g, 2.5 mmol) and dissolved water (26.8 mL). *N*-methyl-D-glucamine (1.54 g, 7.9 mmol) was added followed by EDCI-HCl (1.64 g, 8.6 mmol) and the pH was adjusted to 6.4 with 1.0 M HCl. HOBt hydrate (0.140 g, 1.0 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 18 h. *N*-methyl-D-glucamine (0.77 g, 3.9 mmol) and EDCI-HCl

(0.82 g, 4.3 mmol) were and the pH was maintained at 6 while stirring at ambient temperature for 8 h. EDCI-HCl (0.42 g, 2.2 mmol) was added and stirred at ambient temperature for 17 h. All solvent was then removed in vacuo to leave a brown oil that was purified on C₁₈ silica gel (100% water to 30% AcN in water) to give 1.6 g (56%) of the desired product (ESI: $m/z = 1138 (M + H^+)$).

Example 2: Synthesis of Mn Chelate 4

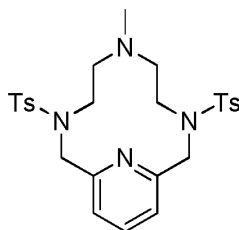
Example 2(i): Synthesis of *N,N'*-((methylazanediyl)bis(ethane-2,1-diyl))bis(4-methylbenzenesulfonamide)



A 1 L round bottomed flask fitted with a magnetic stir bar was charged with *N*-tosylaziridine (49 g, 248 mmol) and AcN (450 mL). 41% aqueous methylamine (12 mL, 121 mmol) was added and stirred at ambient temperature for 36 h. A second aliquot of *N*-tosylaziridine (1.7 g, 8.62 mmol) was added and stirred at ambient temperature for an additional 48 h. The solvent was removed in vacuo and the crude residue was recrystallized from EtOH to give 45 g (87%) of the desired product as a white solid. ¹H NMR (400 MHz, DMSO-*d*₆, δ) 7.68 (4H, m), 7.36 (6H, m), 2.75 (4H, t), 2.38 (6H, s), 2.22 (4H, t), 1.93 (3H, s).

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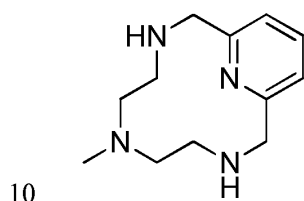
Example 2(ii): Synthesis of protected cyclic 2-arm chelate



A 12L 3-necked round bottomed flask fitted with a reflux condenser and a

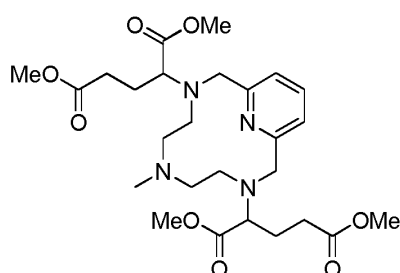
mechanical stirrer was charged with *N,N'*-((methylazanediyl)bis(ethane-2,1-diyl))bis(4-methylbenzenesulfonamide) (93 g, 218.5 mmol) and AcN (8.3 L). 2,6-bis(chloromethyl)pyridine (38.5 g, 218.5 mmol) was added and the resulting solution was heated at 80 ° for 16 h. The reaction mixture was cooled to
5 ambient temperature and solvent was removed in vacuo until crystallization began. The resulting crystals were collected *via* vacuum filtration to afford 86.9 g (75%) of the desired product as a white solid (ESI: $m/z = 530$ ($M + H^+$)).

Example 2(iii): Synthesis of deprotected 2-arm cyclic chelate



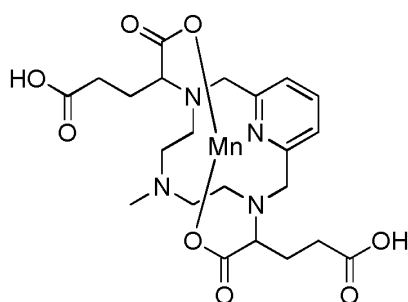
A 1 L 3-necked round bottomed flask fitted with a mechanical stirrer was charged with protected cyclic 2-arm chelate (150 g, 284 mmol) and concentrated sulfuric acid (250 mL, 4.69 mol) and heated at 100 °C for 15 h. The solution was poured onto ice and the pH was adjusted to 7.4 with the
15 addition of 50 wt% NaOH in water resulting in the formation of a white solid. AcN (200 mL) was added and the white solid was removed *via* vacuum filtration. The filtrate was evaporated to dryness to give a brown foam. The foam was dissolved in water (200 mL) and purified with Amberlite A26 resin in its hydroxide form to give 61 g (98%) of the desired product as a tan solid. ¹H
20 NMR (400 MHz, CD₃CN, δ) 7.56 (1H, m), 7.03 (2H, m), 3.76 (4H, s), 2.47 (4H, m), 2.19 (3H, s), 1.95 (4H, s).

Example 2(iv): Synthesis of protected Mn 2-arm C5 chelate



A 500 mL round bottomed flask fitted with a magnetic stir bar was charged with deprotected 2-arm cyclic chelate (20.0 g, 90.8 mmol; obtained according to Example 2(iii)) and AcN (160 mL). Diisopropylethylamine (38.7 mL, 217 mmol) and dimethyl 2-bromopentanedioate (47.7 g, 199.7 mmol) were added and the resulting solution was stirred at 65 °C for 20 h. Diisopropylethylamine (9.75 mL, 54.6 mmol) and dimethyl 2-bromopentanedioate (11.8 g, 49.4 mmol) were added and the resulting solution was stirred at 65 °C for an additional 19h. The solvent was removed in vacuo to leave a red oil. The oil was then dissolved in water (300 mL) and washed with EtOAc (300 mL). The EtOAc layer was then extracted with water (2 x 50 mL) and combined with the initial aqueous layer and the water was removed in vacuo to leave a red oil was used without further purification.

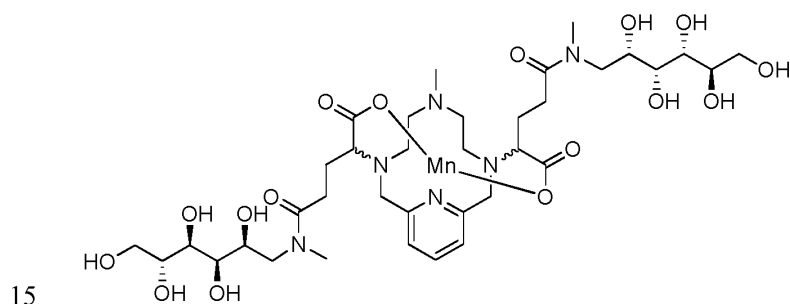
Example 2(v): Synthesis of Mn 2-arm C5 chelate



A 1L round bottomed flask fitted with a magnetic stir bar was charged with protected Mn 2-arm C5 chelate (48.7 g, 90.8 mmol) and water (450 mL). Sodium hydroxide (29.1 g, 726 mmol) was added and stirred at ambient temperature for 2 h. The reaction mixture was washed with EtOAc (250 mL) and the layers were separated. The aqueous layer was washed again with

EtOAc (2 x 100 mL) and the aqueous layer was collected. Manganese chloride tetrahydrate (19.6 g, 99 mmol) was added to the aqueous solution. The pH was adjusted to 7.1 with 6M NaOH and stirred at ambient temperature for 17 h and then at 90 °C for 2.5 h. After cooling to ambient temperature, the pH was adjusted to 10.1 with 50 wt% aqueous NaOH and a fine brown precipitate formed. The precipitate was removed *via* centrifugation at 3000 rcf for 20 min and the supernatant was collected and evaporated to dryness in vacuo. The residue was triturated with MeOH (127 mL) at 40 °C for 1.5 h. The insoluble white solid was removed *via* centrifugation at 3000 rcf for 30 min. The supernatant was evaporated to dryness in vacuo to give an off-white solid which was purified on C₁₈ silica gel (3% AcN in water) to give 36.8 g (75%) of the desired product as an off white solid (ESI: $m/z = 534 (M + H^+)$).

Example 2(vi): Synthesis of Mn Chelate 4

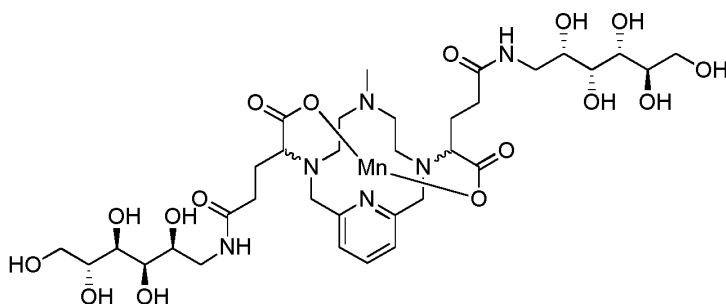


A 250 mL 3-necked round bottomed flask fitted with a magnetic stir bar was charged with Mn 2-arm C5 chelate (4.40 g, 7.27 mmol) and water (76.5 mL). *N*-methyl-D-glucamine (2.98 g, 15.3 mmol) was added followed by EDCI-HCl (3.30 g, 17.2 mmol) and HOBt hydrate (0.20 g, 1.47 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 7 h. EDCI-HCl (1.62 g, 8.45 mmol) was added and the pH was maintained at 6 while stirring for 20 h at ambient temperature. *N*-methyl-D-glucamine (0.75 g, 3.84 mmol) and EDCI-HCl (0.83 g, 4.32 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 3 d. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to

20% AcN in water) to give 3.66 g (57%) of the desired product as a pale yellow solid (ESI: $m/z = 888$ ($M + H^+$)).

Example 3: Synthesis of Mn Chelate 5

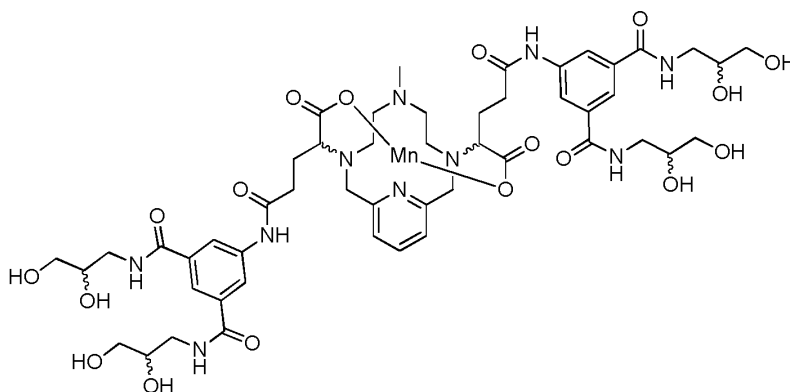
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A 50 mL 2-necked flask fitted with a magnetic stir bar was charged with D-glucamine (0.713 g, 3.94 mmol) and water (19.7 mL). The pH of the resulting solution was adjusted to 7.4 with 1.0 M HCl and Mn 2-arm C5 chelate (1.00 g, 1.87 mmol; obtained according to Example 2(v)) was added followed by EDCI-HCl (0.848 g, 4.42 mmol) and HOBt hydrate (0.121 g, 0.787 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 8 h. D-Glucamine (0.359 g, 1.98 mmol) and EDCI-HCl (0.433 g, 2.26 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 16 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 20% AcN in water) to give 0.782 g (48 %) of the desired product as a pale yellow solid (ESI: $m/z = 860$ ($M + H^+$)).

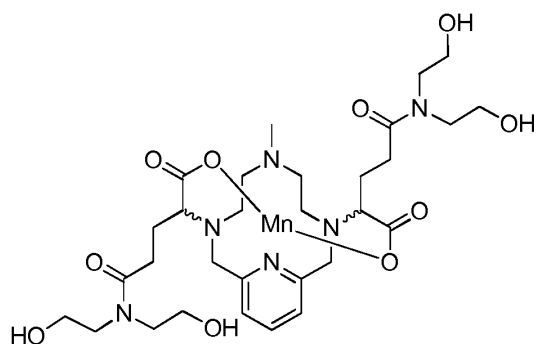
Example 4: Synthesis of Mn Chelate 7

20



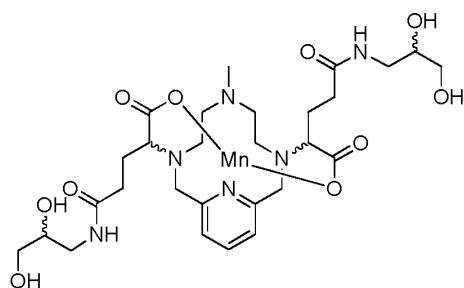
A 2-necked 50 mL flask fitted with a magnetic stir bar was charged with 5-amino-*N,N'*-bis(2,3-dihydroxypropyl)isophthalamide hydrochloride (1.432 g, 3.94 mmol) and water (19.7 mL). The pH of the resulting solution was adjusted to 6 and Mn 2-arm C5 chelate (1.005 g, 1.88 mmol; obtained according to Example 2(v)) was added followed by EDCI-HCl (0.858 g, 4.48 mmol) and HOBt hydrate (0.108 g, 0.799 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 4.5 h. EDCI-HCl (0.868 g, 4.53 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 16 h. EDCI-HCl (0.853 g, 4.44 mmol) and the pH was maintained at 6 while stirring at ambient temperature for 7 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 25% AcN in water) to give 0.600 g (28%) of the desired product as a pale yellow solid (ESI: $m/z = 1152$ (M^+)).

Example 5: Synthesis of Mn Chelate 9



A 2-necked 25 mL flask fitted with a magnetic stir bar was charged with diethanolamine (0.207 g, 1.97 mmol) and water (9.86 mL). The pH of the resulting solution was adjusted to 7 with 1.0 M HCl and Mn 2-arm C5 chelate (0.500 g, 0.956 mmol; obtained according to Example 2(v)) was added followed by EDCI-HCl (0.445 g, 2.32 mmol) and HOBt hydrate (0.045 g, 0.333 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 20 h. Diethanolamine (0.207 g, 1.97 mmol) and EDCI-HCl (0.432 g, 2.25 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 8 h. Diethanolamine (0.207 g, 1.97 mmol) and EDCI-HCl (0.448 g, 2.34 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 15.5 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 30% AcN in water) to give 0.110 g (16%) of the desired product as a pale yellow solid (ESI: $m/z = 708$ ($M + H^+$)).

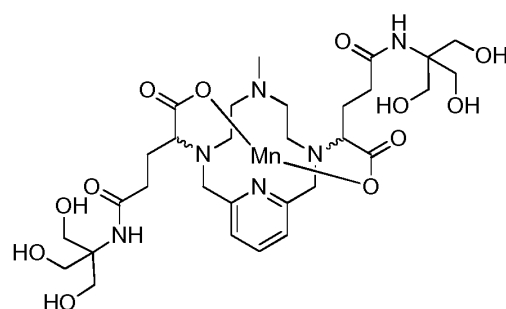
Example 6: Synthesis of Mn Chelate 10



A 25 mL 2-necked flask fitted with a magnetic stir bar was charged with 3-

aminopropane-1,2-diol (0.190 g, 2.03 mmol) and water (10.4 mL). The pH of the resulting solution was adjusted to 7 with 1.0 M HCl and Mn 2-arm C5 chelate (0.603 g, 0.996 mmol; obtained according to Example 2(v)) was added followed by EDCI-HCl (0.473 g, 2.47 mmol) and HOBt hydrate (0.063 g, 0.466 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 7.5 h. 3-Aminopropane-1,2-diol (0.095 g, 1.04 mmol) and EDCI-HCl (0.453 g, 2.36 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 15.5 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 20% AcN in water) to give 0.280 g (41%) of the desired product as a pale yellow solid (ESI: m/z = 680 (M + H⁺)).

Example 7: Synthesis of Mn Chelate 11



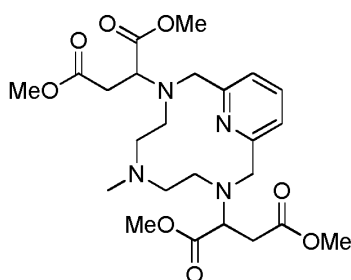
A 100 mL 3-necked round bottomed flask fitted with a magnetic stir bar was charged with Tris base (0.632 g, 5.22 mmol) and water (26.0 mL). The pH of the resulting solution was adjusted to 7 with 1.0 M HCl and Mn 2-arm C5 chelate (1.500 g, 2.49 mmol; obtained according to Example 2(v)) was added followed by EDCI-HCl (1.141 g, 5.95 mmol) and HOBt hydrate (0.160 g, 1.04 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 7.5 h. Tris (0.636 g, 5.25 mmol) and EDCI-HCl (1.177 g, 6.14 mmol) were added and the pH was maintained at 6 while stirring at ambient temperature for 17 h. Tris (0.624 g, 5.15 mmol) and EDCI-HCl (1.133 g, 5.91 mmol) were added and the pH was

maintained at 6 while stirring at ambient temperature for 23 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 20% AcN in water) to give 0.247 g (13%) of the desired product as a pale yellow solid (ESI: $m/z = 740 (M + H^+)$).

5

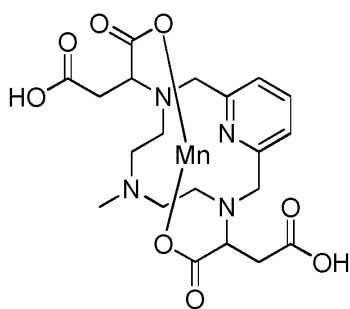
Example 8: Synthesis of Mn Chelate 5a

Example 8(i): Synthesis of protected Mn 2-arm C4 chelate



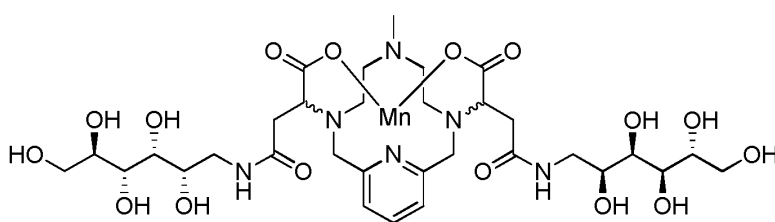
A 250 mL round bottomed flask fitted with a mechanical stirrer was charged with 2-arm cyclic chelate (19.85 g, 90.1 mmol; obtained according to Example 2(iii)), dimethyl maleate (51.94 g, 360.4 mmol), Montmorillinite K10 (36.0 g), and MeOH (36 mL). The resulting suspension was stirred at ambient temperature for 26 h. The insoluble material was removed *via* filtration and the clear orange filtrate was evaporated to dryness. The residue was dissolve in EtOAc (200 mL) and extracted with water (200 mL). The layers were separated and the aqueous layer was evaporated to dryness to give 39.35 g (86%) as an orange solid (ESI: $m/z = 509 (M + H^+)$) which was used without further purification.

Example 8(ii): Synthesis of Mn 2-arm C4 chelate



A 1 L round bottomed flask fitted with a magnetic stir bar was charged with protected Mn 2-arm C4 chelate (39.35 g, 77.2 mmol), sodium hydroxide (24.71 g, 617 mmol) and water (500 mL). The resulting solution was stirred at 45 °C for 4 h. The pH was adjusted to 7 with concentrated HCl and MnCl₄•4H₂O (16.8 g, 84.9 mmol) was added. The pH was maintained at 7 while stirring at 90 °C for 2.5 h before cooling to ambient temperature. The pH was adjusted to 10.1 with 6.0 M NaOH and the resulting precipitate removed *via* centrifugation at 3000 rcf for 20 min. The supernatant was collected and evaporated to dryness in vacuo. The residue was triturated with MeOH (72 mL) at 40 °C for 1.5 h. The insoluble white solid was removed *via* centrifugation at 3000 rcf for 30 min. The supernatant was evaporated to dryness in vacuo to give an off-white solid which was purified on C₁₈ silica gel (3% AcN in water) to give 25.8 g (66 %) of the desired product as an off white solid (ESI: m/z = 506 (M + H⁺)).

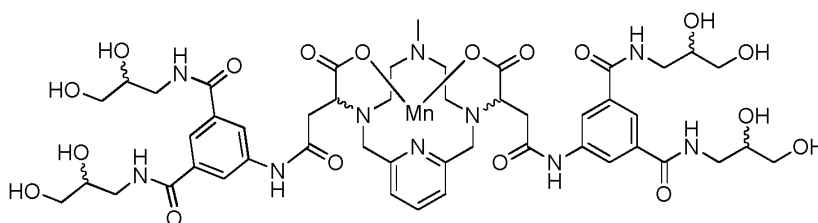
Example 8(iii): Synthesis of Mn Chelate 5a



A 2-necked 50 round bottomed flask fitted with a magnetic stir bar was charged with Mn 2-arm C4 chelate (0.667 g, 1.32 mmol) and water (13.0 mL). Glucamine (0.505 g, 2.79 mmol) was added and the pH was adjusted to 7 with 1.0 M HCl. EDCI-HCl (0.599 g, 3.12 mmol) and HOBt hydrate (0.036 g, 0.266 mmol) were added and the pH was maintained at 6 with addition of 1.0 M HCl

or 1.0 M NaOH as needed while stirring at ambient temperature for 7.5 h. A second aliquot of EDCI-HCl (0.610 g, 3.18 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 16.5 h. A third aliquot of EDCI-HCl (0.610 g, 3.18 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 72 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 30% AcN in water) to give 0.350 g (31%) of the desired product as a pale yellow solid (ESI: $m/z = 832$ ($M + H^+$)).

Example 9: Synthesis of Mn Chelate 7a

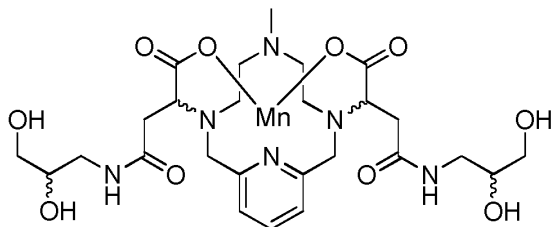


A 3-necked 100 mL round bottomed flask fitted with a magnetic stir bar was charged with 5-Amino-N,N'-bis(2,3-dihydroxypropyl).

isophthalamide hydrochloride (1.516 g, 4.17 mmol) and water (20 mL). The pH of the resulting solution was adjusted to 8 with 1.0 M NaOH and Mn 2-arm C4 chelate (1.000 g, 1.98 mmol; obtained according to Example 8(ii)) was added followed by EDCI-HCl (0.901 g, 4.70 mmol). The pH was maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 6.5 h. A second aliquot of EDCI-HCl (0.895 g, 4.67 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 16.5 h. A third aliquot of EDCI-HCl (0.417 g, 2.18 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 8 h. A fourth aliquot of EDCI-HCl (0.536 g, 2.80 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 17 h. The cloudy reaction mixture was vacuum filtered to remove the solids. The clear, yellow filtrate was evaporated to dryness and the crude product was purified on C₁₈

silica gel (100% water to 20% AcN in water) to give 0.494 g (22 %) of the desired product as a pale yellow solid (ESI: $m/z = 1124$ (M^+)).

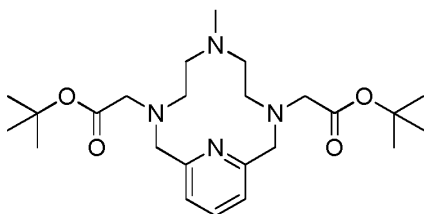
Example 10: Synthesis of Mn Chelate 10a



- 5 A 2-necked 50 mL round bottomed flask fitted with a magnetic stir bar was charged with Mn 2-arm C4 chelate (0.667 g, 1.32 mmol; obtained according to Example 8(ii)) and water (13.0 mL). 3-Amino-1,2-propanediol (0.253 g, 2.77 mmol) and the pH was adjusted to 7 with 1.0 M HCl. EDCI-HCl (0.599 g, 3.12 mmol) and HOBt hydrate (0.036 g, 0.266 mmol) were added and the pH was
- 10 maintained at 6 with addition of 1.0 M HCl or 1.0 M NaOH as needed while stirring at ambient temperature for 7 h. A second aliquot of EDCI-HCl (0.610 g, 3.18 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for 17.5 h. A third aliquot of EDCI-HCl (0.610 g, 3.18 mmol) was added and the pH was maintained at 6 while stirring at ambient temperature for
- 15 70 h. The reaction solution was evaporated to dryness in vacuo and the crude product was purified on C₁₈ silica gel (100% water to 30% AcN in water) to give 0.160 g (19%) of the desired product as a pale yellow solid (ESI: $m/z = 652$ ($M + H^+$)).

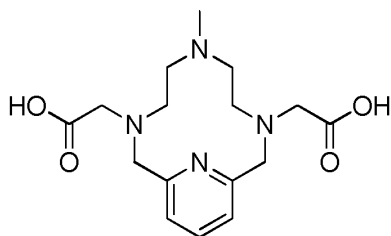
20 **Example 11: Synthesis of Prior Art Mn Chelate**

Example 11(i): Synthesis of protected Mn 0-arm chelate



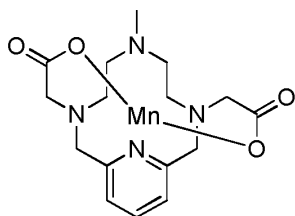
- A 100 mL 3-necked round bottomed flask fitted with a magnetic stir bar and a reflux condenser was charged with protected cyclic 2-arm chelate (4.51 g, 8.53 mmol; obtained according to Example 2(ii)) and concentrated sulfuric acid (18.0 mL) and heated at 100 °C for 18 h. The reaction was cooled to ambient
- 5 temperature and placed in an ice bath prior to adjusting the pH to 9.9 with 50% aqueous NaOH. The resulting suspension was transferred to a 250 mL 3-necked round bottomed flask and anhydrous potassium carbonate (11.78 g, 85.2 mmol) was added followed by AcN (25 mL) and *t*-butylbromoacetate (6.64 g, 34.0 mmol) and the reaction was heated at 70 °C for 3 h. The reaction was
- 10 cooled to ambient temperature and the solids were removed *via* vacuum filtration. The filtrate was extracted with AcN (3 x 50 mL) and the organic layer was evaporated to dryness to give a dark brown oil which was purified on C₁₈ silica gel (100% water to 100% AcN in water) to give 1.28 g (33%) of the desired product as an off white solid. ¹H NMR (400 MHz, CD₃CN, δ) 7.67 (1H, m), 7.12 (2H, m), 5.14 (2H, bs), 3.95 (4H, m), 3.44 (4H, m), 3.28 (6H, m), 3.16
- 15 (2H, m), 2.78 (3H, s), 1.42 (18H, s).

Example 11(ii): Synthesis of deprotected Mn 0-arm chelate



- 20 A 3-necked 100 mL round bottomed flask fitted with a magnetic stir bar and a reflux condenser was charged with protected Mn 0-arm chelate (1.28 g, 2.85 mmol), AcN (8.4 mL) and THF (21 mL). 88% aqueous formic acid (29.1 mL, 556 mmol) was added and the resulting solution was heated at 65 °C for 4 h. A second aliquot of 88% aqueous formic acid (29.1 mL, 556 mmol) was added
- 25 and heating was continued for an additional 9 h. The solvent was removed in vacuo to leave a yellow oil which was used without further purification. ¹H NMR (400 MHz, CD₃OD, δ) 7.74 (1H, m), 7.20 (2H, m), 4.07 (4H, m), 3.65 (4H, m), 2.91 (3H, s), 2.99 (4H, m), 1.92 (4H, m).

Example 11(iii): Synthesis of Prior Art Mn Chelate



A 250 mL round bottomed flask fitted with a magnetic stir bar was charged with deprotected Mn 0-arm chelate (0.959 g, 2.85 mmol) and manganese(II) chloride tetrahydrate (1.119 g, 5.65 mmol). The pH was adjusted to 7.4 with 1.0 M NaOH and 1.0 M HCl as needed and the resulting solution was stirred at ambient temperature for 15.5 h. The pH was then adjusted to 10 with saturated aqueous sodium carbonate and the resulting off-white precipitate was removed
10 *via* vacuum filtration. The filtrate was concentrated to dryness in vacuo and purified on C₁₈ silica gel (100% water to 10% AcN in water) to give 0.511 g (46 % over 2 steps) of the desired product as a pale yellow solid (ESI: $m/z = 390$ (M^+)).

15 **Example 12: In vivo ⁵⁴Mn biodistribution studies in rats**

⁵⁴Mn labeled chelates for biodistribution studies were prepared using the following method. To a 3 mL glass vial fitted with a magnetic stir bar was added the respective manganese containing chelate (1 mg) and 1.0 M ammonium formate, pH = 4 (0.5 mL) (pH = 5 for prior art Mn Chelate). ⁵⁴MnCl₂
20 in 1.0 M HCl (~500 μ Ci) was then added and the resulting solution was heated at 40 °C for 16 h. The resulting solution was purified *via* preparative HPLC to remove unchelated Mn. The radioactive fraction was collected and evaporated to dryness in vacuo. The radioactive residue was taken up in water containing non-radioactive Mn chelate (0.310 M) such that ~30 μ Ci of radioactivity was
25 formulated in a dose of 0.620 mmol Mn/kg with an injection volume of 2 mL/kg.

The experimental protocol conformed to the Guide for the Care and Use of Laboratory Animals and was approved by the IACUC at General Electric Global

Research (Niskayuna, NY). Female Sprague-Dawley rats (130-150g; Charles River Laboratories; Massachusetts; USA) were housed in standard cages, provided with *ad libitum* access to standard commercial food and water, and were maintained on an alternating 12-hr light-dark cycle in rooms with controlled temperature and humidity. Prior to injection of ^{54}Mn labelled chelates, rats were anesthetized *via* inhaled 3% Isoflurane (Piramal, NDC 66794-013-25; EZ-Anesthesia EZ700 Isoflurane Vaporizer, S/N 107). The injection site was prepped with alcohol wipes and a temporary 27Ga catheter (Surflo SROX2419V) was placed in a tail vein. 30 μCi (0.74 MBq) of ^{54}Mn labelled chelate formulated with respective non-radioactive Mn(II) based chelate was dosed at 0.620 mmol non-radioactive Mn chelate/kg at an injection volume of 2 mL/kg was injected at a rate of 1mL/min. Following injection animals were individually housed in wire bottom cages lined with filter paper until first urine void was collected. The rats were then cohoused in standard long term caging. 7 days post injection, the animals were sacrificed by CO_2 immersion and organs and tissues of interest were removed and assayed for radioactivity using a Wizard 2480 gamma counter (Perkin Elmer, Beaconsfield, UK).

Naïve rats (Charles River Laboratories; Massachusetts; USA) received a single dose of 0.620 mmol/kg (approximately 30 μCi , 0.740 MBq) of test item *via* tail vein by injection. Additionally, one group of animals received osmolality matched saline (concentrated NaCl for injection: APP Pharmaceuticals part # NDC 63323-187-30 Lot # 6008656 mixed with Sterile Water for Injection: Hospira part # NDC 0409-7990-09 Lot # 49-396-DKas) as negative control (Table 1). After sacrifice, the organs and tissues were removed and assayed for residual radioactivity (i.e. ^{54}Mn organ retention) 7 days post single administration.

Table 1. Study design for the ^{54}Mn Biodistribution study in rats. Test item: Prior Art Mn Chelate; Mn Chelate 3 and Mn Chelate 4. Residual radioactivity (%ID) was assessed 7 days following single iv administration.

Group number	Test item	Number of animals/sex	Radioactive dose (μCi)	Chemical dose (mmol/kg)	In life time
1	[^{54}Mn] Prior Art Mn Chelate ¹	4/F	30	0.620	7 day
2	[^{54}Mn] Mn Chelate 3	4/F	30	0.620	7 days
3	[^{54}Mn] Mn Chelate 4	4/F	30	0.620	7 day
4	Saline	4/F	0	0	7 day

The aim of this study was to evaluate the tissue distribution in naïve rats 7 days after a single injection of Mn(II) based chelates labelled with ^{54}Mn (radioactive isotope). Residual radioactivity (e.g., %ID) was measured in the relevant collected tissues (Table 2). The Mn(II) based chelates evaluated showed levels of ^{54}Mn retention within physiological manganese level variability in almost all organs and tissues collected, and trace amounts were present in the excretory organs. Detection of ^{54}Mn in the liver and kidney was expected for all compounds evaluated as those organs are part of the primary route of excretion for all MR contrast agents. The Mn(II) based chelates demonstrated reduced distribution to the heart and the brain compared to literature data with $^{54}\text{MnCl}_2$. Indeed, the lower levels (e.g., within endogenous level variability) of ^{54}Mn detected in the brain for the Mn Chelate 3 and Mn Chelate 4 are of great interest because brain is one of the toxicity target organ for Mn(II). Surprisingly, the lower levels ^{54}Mn in the tibia/fibula and femur for Mn Chelate 3 and 4 are also indicative of improved *in vivo* stability of this class of compounds when

- compared to the prior art Mn Chelate considering the bones act as a reservoir of free metal ions (e.g., Mn(II)). The biodistribution profiles of the three Mn(II) based chelates demonstrated the *in vivo* stability of the paramagnetic complexes is a property can be modulated by the structural design of the chelate moiety with Mn Chelate 3 and Mn Chelate 4 showing an improved stability compared to the prior art Mn Chelate.

Table 2: %ID $\pm$ standard deviation for collected tissues. Retained activity has been measured 7days post single administration of 0.62 mmol non-radioactive Mn chelate/kg dose containing $\sim 30 \mu\text{Ci}$ of ^{54}Mn labelled chelate.

Tissue	Prior Art Mn Chelate ^a	Mn Chelate 4 ^b	Mn Chelate 3 ^c
Brain	$0.007 \pm 0.002\%$	$0.003 \pm 0.000\%$	$\leq \text{LOD}$
Pituitary Gland	$\leq \text{LOD}$	$\leq \text{LOD}$	N.M.
Olfactory Bulb	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Liver	$0.072 \pm 0.017\%$	$0.075 \pm 0.011\%$	$0.091 \pm 0.017\%$
Kidney	$0.012 \pm 0.002\%$	$0.038 \pm 0.017\%$	$0.026 \pm 0.005\%$
Spleen	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Bladder	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Heart	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Lungs	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Muscle	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Skin	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$
Blood	$\leq \text{LOD}$	$\leq \text{LOD}$	$\leq \text{LOD}$

Tibia/Fibula	0.002 ± 0.000%	≤ LOD	≤ LOD
Femur	0.003 ± 0.001%	≤ LOD	N.M.

^aLoD = 0.002% ID, n = 8; ^bLoD = 0.002% ID, n = 8; ^cLoD = 0.005% ID, n = 3

Example 13: Water solubility of Mn(II) based chelates

The solubility of Mn(II) based chelates was confirmed by dissolving purified Mn(II) based chelates (~ 99% purity) in a prescribed volume of solvent (Millipore water 18.2 MegaOhm from a Millipore BioCell Benchtop unit) to provide a solution of given volume. Solutions were visually inspected for homogeneity and filtered through a 0.45 um PTFE filter membrane if necessary. The assessment was carried out at 25 °C. Final sample concentrations were confirmed by determination of final Mn(II) concentration *via* ICP-MS (Spectro Arcos FHS12, S/N 10003910 or S/N 12006120).

The size of the paramagnetic complex can affect the water solubility hence the distribution into the extracellular space and clearance rate from the body. An adequate water solubility is also required to maintain low the volume of injection to facilitate the administration of the contrast agents to patients. To this end, typically commercially available Gd(III) contrast agents are formulated at a concentration of 0.5 M. The solubility of the Mn(II) based chelates were confirmed within standard solubility range (>0.5 M) independently from the increased molecular size observed for some compounds (Table 3).

20

Table 3: MW and solubility range for exemplary Mn(II) based chelates comprised in this invention. Solubility was assessed at 25 °C.

Compound	MW (g/mol)	Solubility in water at 25 °C (M)
Prior Art Mn	389.31	> 0.5

Chelate		
Mn Chelate 3	1137.09	> 0.5
Mn Chelate 4	887.3	> 0.5
Mn Chelate 5	859.78	> 0.5
Mn Chelate 7	1152.07	> 0.5
Mn Chelate 9	707.67	> 0.5
Mn Chelate 10	679.62	> 0.5
Mn Chelate 5a	831.72	> 0.5
Mn Chelate 10a	651.57	> 0.5

Example 14: In vitro Proton Relaxivity and Nuclear Magnetic Relaxation Dispersion (NMRD) profiles of Mn(II) based chelates

Both the longitudinal and transverse relaxation times were measured in human serum (BioreclamationIVT, Cat# HMSRM-M) to reflect the efficiency of the Mn(II) based chelates in an environment close to physiological. The relaxivity assessment was carried out at a concentration ranging from 5 to 0 mM Mn(II), at 40 °C using a Minispec Mq benchtop NMR relaxometer (Bruker Instruments, Rheinstetten, Germany) operating at 60 MHz (1.4T) with an inversion recovery pulse sequence. The longitudinal and transverse relaxivities of the complexes (e.g., r_1 and r_2 respectively) were calculated by plotting the reciprocal of their relaxation time versus the manganese concentration as determined *via* ICP-MS (Spectro Arcos FHS12, S/N 10003910 or S/N 12006120) for each Mn(II) based chelates. The dependence of T_1 by B_0 (i.e., magnetic field) applied was assessed *via* the acquisition of ^1H Nuclear Magnetic Relaxation Dispersion (NMRD) profiles. A dedicated Stelar SMARTracer Fast Field Cycling relaxometer (0.01-10 MHz) and a Bruker WP80 NMR electromagnet adapted to

- variable field measurements (20-80 MHz) and controlled by a SMARTTracer PC-NMR console was used to record the ^1H NMRD profiles over an extended range of Larmor Frequencies (from 0.01 to 80 MHz). The temperature was monitored by a VTC91 temperature control unit and maintained by a gas flow.
- 5 The temperature was determined by previous calibration with a Pt resistance temperature probe. High field relaxivities were measured on a Bruker AVANCE NMR spectrometer at 400 MHz. A total of 25 data points per NMRD profile were recorded at each temperature, pH 6.9 and with a manganese concentration in the samples of 6.99, 6.78 and 4.45 mM for the prior art Mn
- 10 Chelate, Mn Chelate 4 and Mn Chelate 3, respectively. The concentration of Mn(II) in all samples was verified by Bulk Magnetic Susceptibility (BMS) measurements. Relaxivity was computed by subtracting the relaxation rate of the medium (distilled water) from the relaxation rate of the Mn(II) complex solution at each field strength and dividing the difference by the manganese
- 15 concentration verified by BMS measurements.

The linear fit ($R^2 > 0.99$ for all compounds examined) of $1/T_1$ and $1/T_2$ as a function of Mn concentration generated the r_1 or r_2 values reported in Table 4 for human serum.

- 20 *Table 4: Relaxivities r_1 and r_2 in human serum at 60 MHz and 40 °C for exemplary Mn(II) based chelates.*

Compound	r_1 ($\text{mM}^{-1}\text{s}^{-1}$)	r_2 ($\text{mM}^{-1}\text{s}^{-1}$)
Prior Art Mn Chelate	3.0	7.4
Mn Chelate 3	8.0	18.3
Mn Chelate 4	5.3	13.7
Mn Chelate 5	5.2	13.1
Mn Chelate 7	6.0	12.8

Mn Chelate 9	4.3	12.0
Mn Chelate 10	4.3	11.6
Mn Chelate 11	4.6	12.3
Mn Chelate 5a	3.7	7.9
Mn Chelate 10a	3.8	8.8

- The relaxivity measurements demonstrated all Mn(II) based chelates are viable and within the standard relaxivity (i.e., r_1 and r_2) ranges of commercially-available MRI contrast agents ($r_1 \geq 3 \text{ mM}^{-1}\text{s}^{-1}$). Of specific interest is the r_1 (i.e., longitudinal relaxivity) value of the Mn(II) based chelates which represents the ability of the chelates to generate T_1 (or positive) contrast *in vivo* following iv administration. Whereas, the r_2 (i.e., transverse relaxivity) value represents the ability of the Mn(II) based chelates to generate T_2 (or negative) contrast following iv administration.
- ^1H NMRD profiles were recorded for the prior art Mn Chelate and Mn Chelate 4 (Figure 2 and Figure 3, respectively). Both Mn(II) based chelates evaluated demonstrated a viable ^1H NMRD profile with lower longitudinal relaxivities than the Mn(II) aqua ion and only one dispersion in the profile around 1 MHz. The NMRD profile of Mn Chelate 4 (Figure 3) showed a small r_1 hump in the frequency region between 60 and 80 MHz ($\sim 1.5\text{T}$) which may be advantageous for future clinical imaging application with an improved efficiency of the Mn(II) based chelate at clinically relevant magnetic field strength. This high field r_1 hump is due to a small decrease in the tumbling rate related to the larger molecular size of the compound.

20

Example 15: Dissociation Kinetics of Mn(II) based chelates

Kinetic inertness was evaluated at slightly acidic pH due to the slow rate of dissociation of the paramagnetic complex at physiological pH and to the

potential hydrolysis of the metal ions at the concentrations used for the experiments and at pH values close to physiological.

Zn²⁺ exchange

The dissociation kinetics of Mn(II) based chelates (concentration 1 mM) of the invention was assessed *via* Zn²⁺ transmetallation recording the time-dependent variation of the longitudinal relaxation time (i.e., T₁). The assessment was completed in a set of experiments including for the prior art Mn Chelate different concentrations of competing metal ion (5, 10, 20, 40 equivalents of Zn²⁺); at 25 °C and different pH (pH: 5.1; 5.4; 5.7). The dissociation kinetics for Mn Chelate 4 (concentration 1 mM) was assessed in the presence of 5 eq of Zn²⁺ at 25 °C and pH 5.1 and 5.7. For both assessments, the reaction mixture contained 0.15 M NaCl and 50 mM N-methyl piperazin buffer (i.e., NMP). The longitudinal relaxation time changes were monitored at 1 MHz for the prior art Mn Chelate and at 0.01 MHz for Mn Chelate 4. Indeed, the release of the free Mn²⁺ ion induced by Zn²⁺ leads to a decrease of the relaxation time for both Mn(II) based chelates evaluated in all experimental conditions. The acquisition frequencies for this set of experiments have been selected based on the difference between the observed relaxivity of the Mn(II) aqua ion and the Mn(II) based chelates (e.g., prior art Mn Chelate and Mn Chelate 4) in order to have enough differentiation between the two chemical species. The frequencies have been selected based on the ¹H NMRD profiles as displayed in Figure 1 for prior art Mn Chelate, Mn Chelate 4 and MnCl₂.

Cu²⁺ exchange

The dissociation kinetics of the prior art Mn Chelate, Mn Chelate 4 and Mn Chelate 3 at a concentration of 0.2 mM was assessed *via* Cu²⁺ transmetallation recording the time-dependent change of the UV-Vis absorbance in the presence of an excess of competing metal ion (10 and 40 equivalents of Cu²⁺); at 25 °C and different pH (pH: 5.0; 5.2; 5.4). For all assessments, the reaction mixture contained 0.15 M NaCl; 50 mM NMP. The λ for the acquisition of the UV-Vis spectra was selected based on the difference between the observed

absorbance for the Mn(II) based chelates (e.g., prior art Mn Chelate, Mn Chelate 3 and Mn Chelate 4) and the newly formed Cu^{2+} - complex in order to have the best differentiation between the two chemical species. The UV-Vis spectra were acquired at $\lambda = 300$ nm on a Perkin-Elmer Lambda 19 spectrophotometer. Indeed, the displacement of Mn(II) ion induced by Cu^{2+} led to an increase of the observed absorbance at $\lambda = 300$ nm for all Mn(II) based chelates in all experimental conditions. This increase is due the formation of the Cu^{2+} - complex.

10 Results of Transmetallation Experiments

Zn^{2+} and Cu^{2+} transmetallation were studied by using an excess of the exchanging metal ion to demonstrate kinetic inertness of Mn(II) based chelates. For any of the transmetallation experiments carried out with the prior art Mn Chelate (e.g., at different pH; different Zn^{2+} or Cu^{2+} concentration) it was evident that the variation of the relaxation rate T_1 (for the Zn^{2+} -exchange; Figure 4) or the variation of the UV-Vis absorbance (for the Cu^{2+} -exchange; Figure 5) caused by competing metal ion was a "single phase" process better described as a mono-exponential function. Indeed, the prior art Mn Chelate showed an exchange reaction governed by a pseudo-first order equation (1) with the reaction rate directly proportional to the total concentration of Mn(II) based chelates. The rate of dissociation described by k_{obs} was calculated via equation (1) where $[\text{MnL}]_{\text{tot}}$ is the total concentration of Mn(II) based chelates and t is the observation time.

$$25 \quad - \frac{d[\text{MnL}]_{\text{tot}}}{dt} = k_{\text{obs}} [\text{MnL}]_{\text{tot}} \quad (\text{Equation 1})$$

In contrast to the prior art Mn Chelate, for Mn Chelate 4 and Mn Chelate 3 the time dependent curves of the UV-Vis absorption in the transmetallation reaction with Cu^{2+} were not described by a monoexponential function, but showed a

biphasic nature (i.e., two steps-mechanisms dissociation process). The biphasic nature of the of the Mn(II) – Cu²⁺ exchange process was evident and confirmed for Mn Chelate 3 and Mn Chelate 4 at all pH and competing metal ion concentrations assessed. The comparison between the kinetic curves for the prior art Mn chelate, Mn Chelate 3 and Mn Chelate 4 describing the transmetallation with Cu²⁺ at different pH are presented in Figure 6 and Figure 7. The curves profile clearly demonstrated the different dissociation mechanism of the three compounds when examined in the same experimental conditions.

To confirm the biphasic nature of the kinetic dissociation curves for Mn Chelate 3 and Mn Chelate 4 the transmetallation reaction with Zn²⁺ was assessed for Mn Chelate 4. The time dependent curves of the longitudinal relaxation time (i.e., T₁) were recorded at pH 5.1 and 5.7 (Figure 8) and they confirmed the biphasic behaviour of the kinetic curves hence of the dissociation process for Mn Chelate 4.

Mn Chelate 3 and Mn Chelate 4 showed an exchange reaction governed by the sum of two independent exponential functions. These biphasic kinetic curves could be mathematically well fitted with the biexponential equation (2) where A is the observed absorbance; b , A_1 and A_2 are constants specific for the biphasic dissociation process for a Mn(II) based chelate; k_{obs1} and k_{obs2} are the rate constants describing the biphasic dissociation and t is the observation time.

$$A = b - A_1 e^{-k_{obs1} t} - A_2 e^{-k_{obs2} t} \quad (\text{Equation 2})$$

The rates of the biphasic dissociation for Mn Chelate 3 and Mn Chelate 4 described by k_{obs1} and k_{obs2} and of the monophasic dissociation for the prior art Mn Chelate described by k_{obs} were calculated via equation (2) and (1) respectively for the different experimental conditions utilized in the set of experiments.

Table 5: Observed rate constants k_{obs1} and k_{obs2} calculated by a monoexponential (for the prior art Mn Chelate) or biexponential equations (for Mn Chelate 3 and Mn Chelate 4) for Cu^{2+} transmetallation.

		Prior Art Mn Chelate	Mn Chelate 4		Mn Chelate 3	
	$\text{C}_{\text{Cu}^{2+}} \text{ (M)}$	$k_{\text{obs}} \text{ (min}^{-1}\text{)}$	$k_{\text{obs1}} \text{ (min}^{-1}\text{)}$	$k_{\text{obs2}} \text{ (min}^{-1}\text{)}$	$k_{\text{obs1}} \text{ (min}^{-1}\text{)}$	$k_{\text{obs2}} \text{ (min}^{-1}\text{)}$
pH=5.4	0.002	0.017	0.201	0.001		
pH=5.2	0.002	0.022	0.240	0.0009	0.303	0.0015
pH=5.0	0.002	0.034	0.340	0.0013	0.483	0.0023
	0.004	0.032				
	0.008	0.035	0.190	0.0009	0.378	0.0024

- 5 From the qualitative comparison of the kinetic curves and preliminary k_{obs} it was evident that Mn Chelate 3 and Mn Chelate 4 dissociate with a different mechanism described by a biexponential function and at a slower rate compared to the prior art Mn Chelate. To quantitatively compare the kinetic inertness of these Mn(II) based chelates, the direct comparison of the evolution
- 10 of the UV-Vis absorbance at 300 nm was recorded for the Cu^{2+} exchange reaction. Direct comparison of the UV-Vis absorbance allowed quantification of the conversion of the Mn(II) based chelates into Cu^{2+} based chelates during the transmetallation reaction which can be correlated to the kinetic inertness of the Mn(II) complex. The “conversion” was calculated following equation (3), where
- 15 A_t is the absorbance at a time t (or end of the reaction), A_0 is the absorbance at time zero (or beginning of the acquisition) and A_{eq} is the absorbance at the

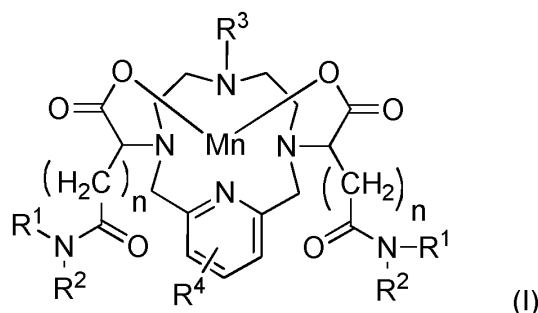
equilibrium.

$$\text{Conversion} = \frac{A_t - A_0}{A_{eq} - A_0} \quad (\text{Equation 3})$$

- The direct comparison of the conversation calculated for any of the transmetallation experiments carried out with the prior art Mn Chelate, Mn Chelate 3 and Mn Chelate 4 (e.g., at different pH; different Zn^{2+} or Cu^{2+} concentration) demonstrated that the prior art Mn Chelate reaches a full conversion at much shorter time point than Mn Chelate 3, and the complex Mn Chelate 4 dissociates even slower. The conversion caused by competing Cu^{2+} was calculated and displayed in Figures 9 and 10.
- With the same mathematical approach, the conversion caused by transmetallation reaction with Zn^{2+} was also compared for the prior art Mn Chelate and Mn Chelate 4 (Figure 11). This assessment clearly demonstrated the superior kinetic inertness of Mn Chelate 4 with respect to the prior art Mn Chelate.
- Therefore, Mn Chelate 3 and Mn Chelate 4 demonstrated a different and slower dissociation mechanism in the Cu^{2+} and Zn^{2+} transmetallation with respect to the prior art Mn chelate. Surprisingly, an improved kinetic inertness was demonstrated by directly comparing the conversion of the three compounds occurred during the transmetallation reaction between the MnL (i.e., Mn(II) complex) and Zn^{2+} or Cu^{2+} under the same experimental conditions. All dissociation kinetics results showed an evident improvement in overall kinetic inertness for Mn Chelate 3 and Mn Chelate 4 with respect to the prior art Mn Chelate as reference. Indeed, Mn Chelate 4 resulted as the most kinetically inert compound examined in all experimental conditions. It is possible to hypothesize that the presence of side chains with -OH groups can wrap around the smaller Mn(II) metal successfully protecting the Mn from dissociation hence contributing to an increased kinetic inertness of this class of Mn(II) based chelates.

Claims

(1) A compound of Formula I:



5 or a salt or solvate thereof, wherein:

each R¹ is independently selected from the group comprising C₁₋₂₀ hydroxyalkyl, C₁₋₆ alkyl, C₃₋₆ aryl optionally-substituted with one or more substituents selected from halo and -C(=O)-NH-C₁₋₆ hydroxyalkyl, or a carbohydrate moiety;

10 each R² is independently selected from the group comprising C₁₋₂₀ hydroxyalkyl, C₁₋₆ alkyl or hydrogen;

R³ is selected from the group comprising C₁₋₃ alkyl or -(CH₂)_m-C(=O)-NR⁵R⁶ wherein m is an integer from 2-5, and R⁵ and R⁶ are as respectively defined for R¹ and R²;

15 R⁴ represents 0-3 substituents selected from the group comprising hydroxy, C₁₋₆ alkyl and C₁₋₆ hydroxyalkyl; and,

each n is an integer from 0-4;

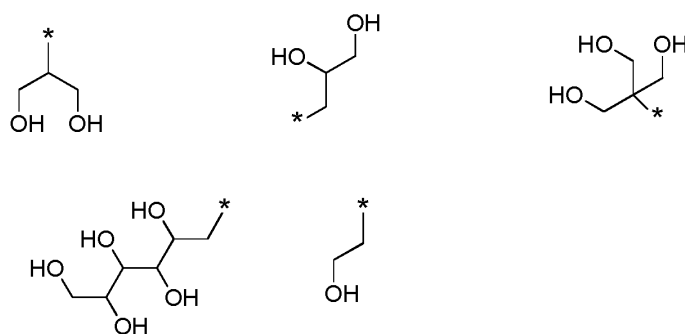
and wherein the compound of Formula I comprises at least two hydroxy groups.

20 (2) The compound as defined in Claim 1 wherein each R¹ is C₁₋₁₂ hydroxyalkyl.

(3) The compound as defined in either Claim 1 or Claim 2 wherein each R¹ is C₃₋₆ hydroxyalkyl.

- (4) The compound as defined in any one of Claims 1-3 wherein each R¹ is C₆ hydroxyalkyl.
- (5) The compound as defined in any one of Claims 1-3 wherein each R¹ is independently selected from the group comprising:

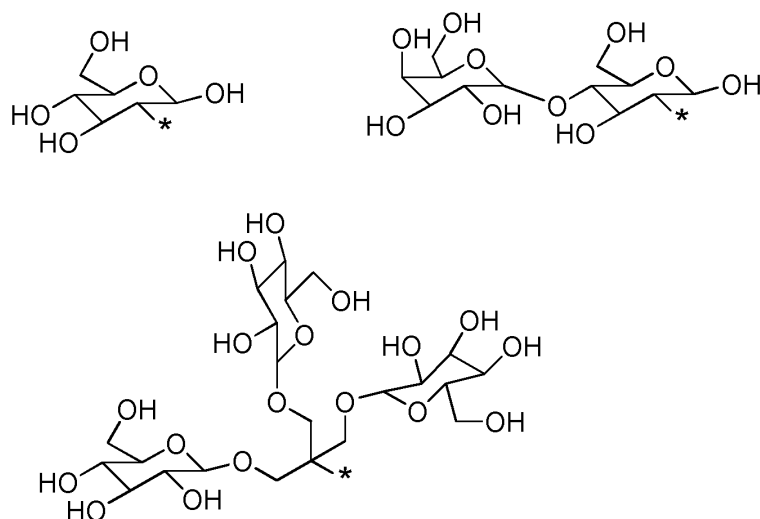
5



wherein in each case the asterisk denotes the point of attachment to the rest of the compound of Formula I.

- (6) The compound as defined in Claim 1 wherein each R¹ is independently selected from the group comprising:

10

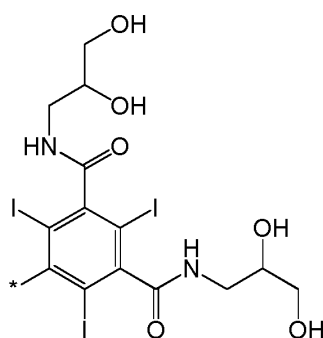


wherein in each case the asterisk denotes the point of attachment to the rest of the compound of Formula I.

- (7) The compound as defined in Claim 1 wherein each R¹ is a C₃₋₆ aryl

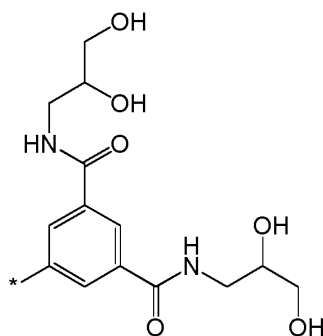
substituted with one or more substituents selected from halo and –
C(=O)-NH-C₁₋₆ hydroxyalkyl.

- (8) The compound as defined in Claim 7 wherein said C₃₋₆ aryl is phenyl.
- (9) The compound as defined in Claim 7 or Claim 8 wherein said halo is
5 iodo.
- (10) The compound as defined in any one of Claims 7-9 wherein said –
C(=O)-NH-C₁₋₆ hydroxyalkyl is –C(=O)-NH-CH₂-C(OH)-CH₂-C(OH).
- (11) The compound as defined in any one of Claims 7-10 wherein each R¹ is:



- 10 wherein the asterisk denotes the point of attachment to the rest of the
compound of Formula I.

- (12) The compound as defined in any one of Claims 7-10 wherein each R¹ is:

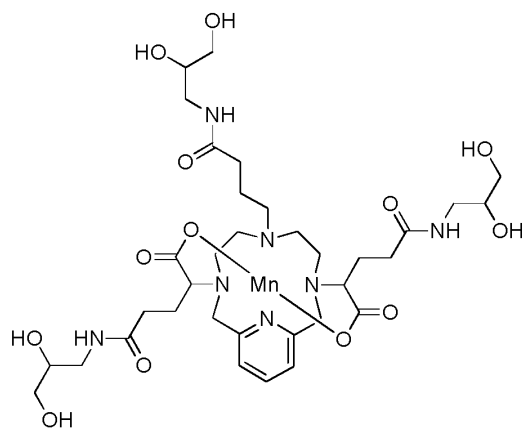


- 15 wherein the asterisk denotes the point of attachment to the rest of the
compound of Formula I.

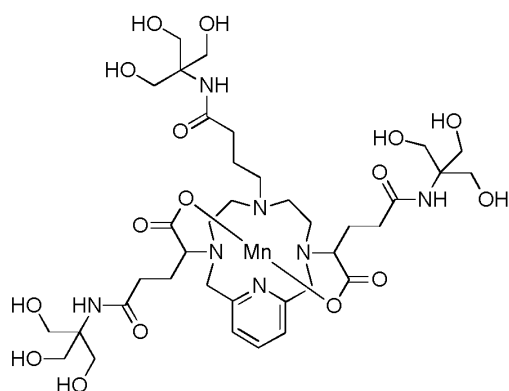
- (13) The compound as defined in any one of Claims 1-12 wherein each R¹ is
the same.

- (14) The compound as defined in any one of Claims 1-13 wherein each R² is C₁₋₃ alkyl.
- (15) The compound as defined in Claim 14 wherein each R² is methyl.
- (16) The compound as defined in any one of Claims 1-13 wherein each R² is hydrogen.
- (17) The compound as defined in any one of Claims 1-13 wherein each R² is C₁₋₂₀ hydroxyalkyl.
- (18) The compound as defined in Claim 17 wherein each R² is C₁₋₆ hydroxyalkyl.
- (19) The compound as defined in Claim 18 wherein each R¹ is C₁₋₆ hydroxyalkyl.
- (20) The compound as defined in any one of Claims 1-19 wherein each R² is the same.
- (21) The compound as defined in any one of Claims 1-20 wherein each n is an integer from 1-3.
- (22) The compound as defined in Claim 21 wherein each n is 1.
- (23) The compound as defined in Claim 21 wherein each n is 2.
- (24) The compound as defined in Claim 21 wherein each n is 3.
- (25) The compound as defined in any one of Claims 1-24 wherein R³ is C₁₋₃ alkyl.
- (26) The compound as defined in Claim 25 wherein R³ is methyl.
- (27) The compound as defined in any one of Claims 1-24 wherein R³ is –(CH₂)_m-C(=O)-NR⁵R⁶ as defined in Claim 1.
- (28) The compound as defined in Claim 27 wherein R⁵ is as defined for R¹ in any one of Claims 2-12.
- (29) The compound as defined in either Claim 27 or Claim 28 wherein R⁶ is as defined for R² in any one of Claims 14-18.
- (30) The compound as defined in any one of Claims 27-29 wherein m is 3.

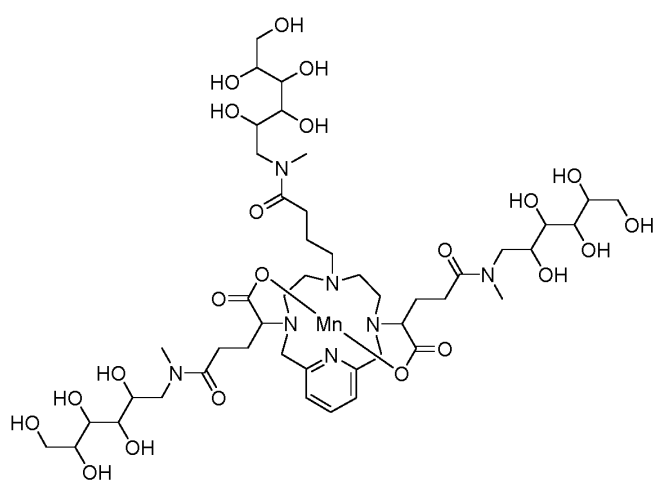
- (31) The compound as defined in Claim 30 wherein n is 2.
- (32) The compound as defined in any one of Claims 1-31 wherein R⁴ represents 0 substituents.
- (33) The compound as defined in any one of Claims 1-31 wherein R⁴ represents 1 or 2 hydroxy groups.
- (34) The compound as defined in Claim 33 wherein R⁴ represents 2 hydroxy groups at the meta positions of the pyridyl ring.
- (35) The compound as defined in any one of Claims 1-34 which comprises at least 4 hydroxy groups.
- (36) The compound as defined in Claim 35 which comprises 4-15 hydroxy groups.
- (37) The compound as defined in Claim 36 which comprises 5-10 hydroxy groups.
- (38) The compound as defined in any one of Claims 1-37 wherein said Mn is an enriched isotope of Mn selected from the group comprising ⁵²Mn and ⁵⁴Mn.
- (39) The compound as defined in Claim 1 which is selected from any one of the following compounds:



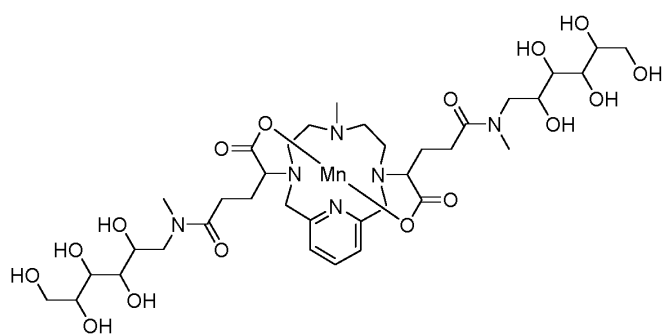
Mn Chelate 1 Racemate



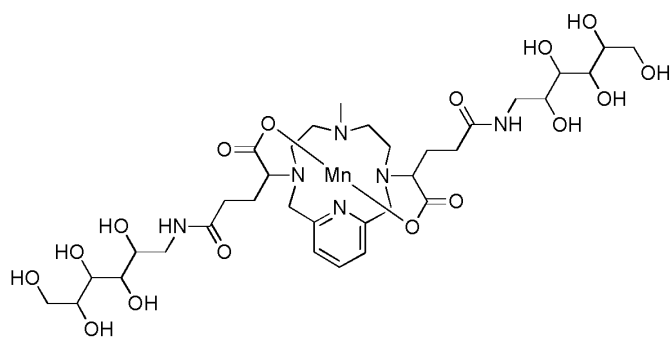
Mn Chelate 2 Racemate



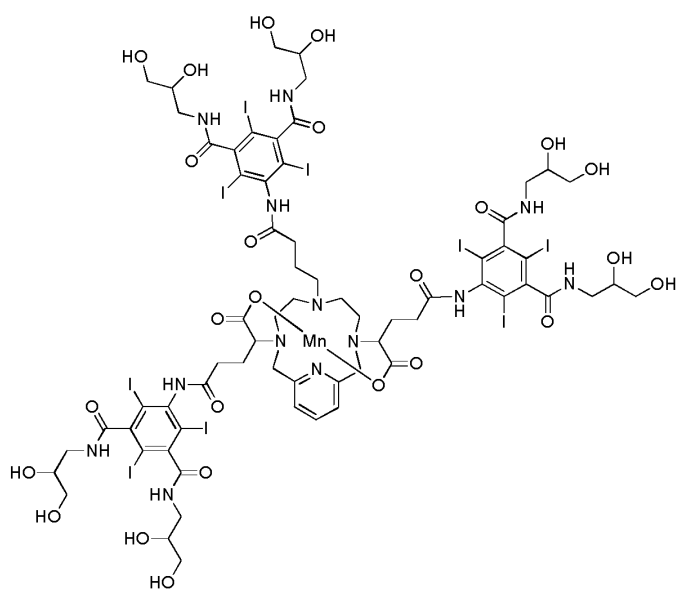
Mn Chelate 3 Racemate



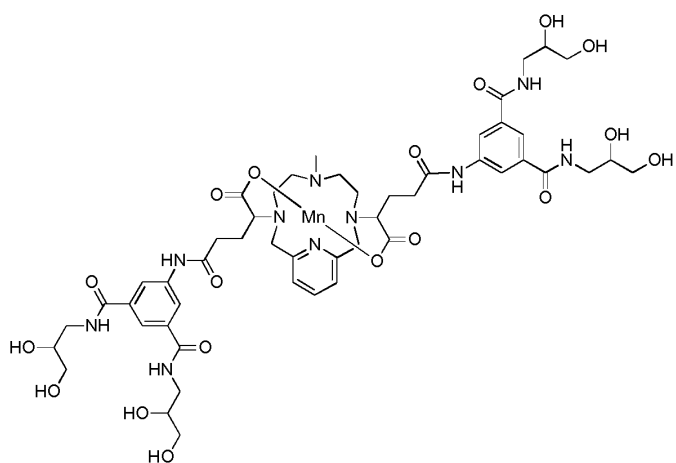
Mn Chelate 4 Racemate



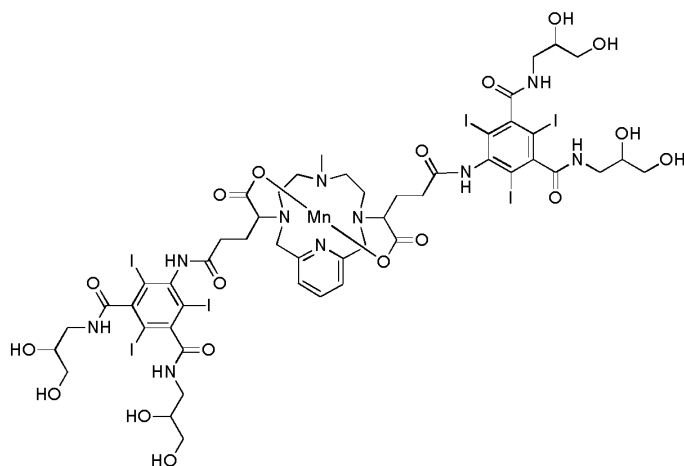
Mn Chelate 5 Racemate



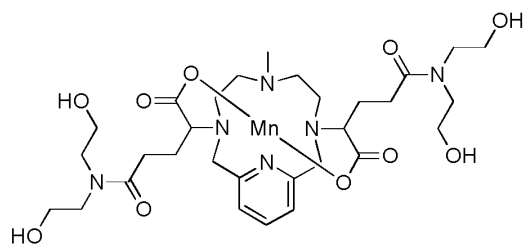
Mn Chelate 6 Racemate



Mn Chelate 7 Racemate

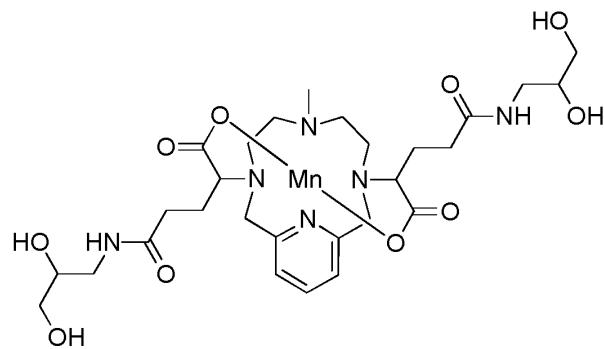


Mn Chelate 8 Racemate

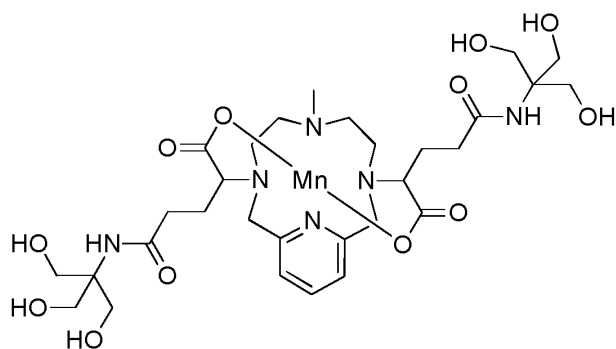


Mn Chelate 9 Racemate

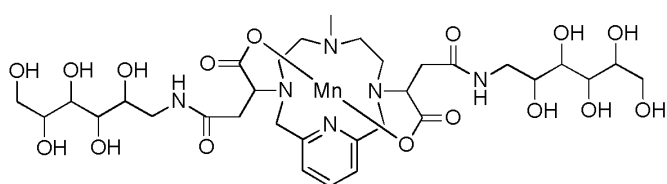
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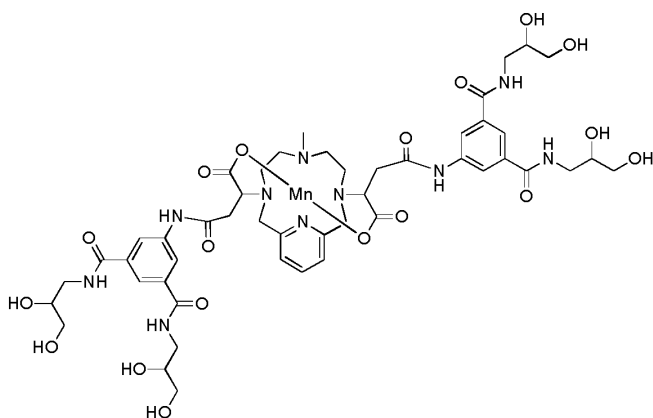
Mn Chelate 10 Racemate



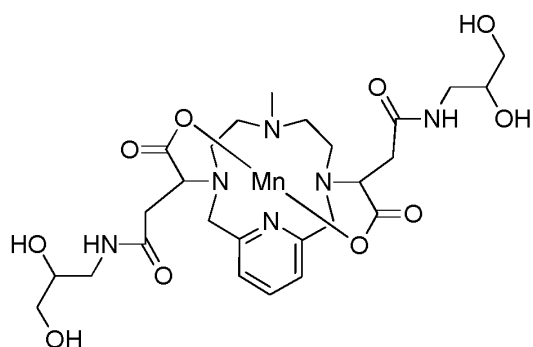
Mn Chelate 11 Racemate



Mn Chelate 5a Racemate

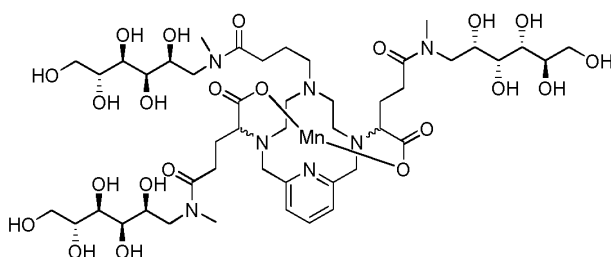


Mn Chelate 7a Racemate

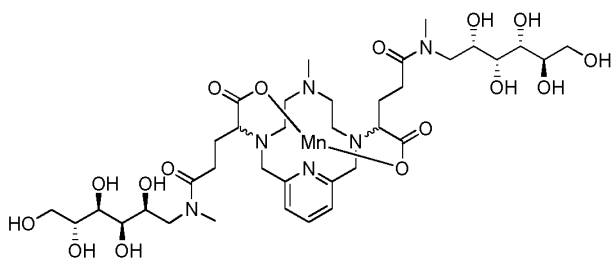


Mn Chelate 10a Racemate

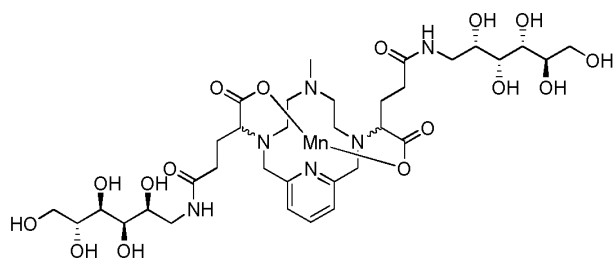
- (40) The compound of Formula I as defined in any one of Claims 1-39 which is diastereomerically pure.
- 5 (41) The compound as defined in Claim 40 which is selected from any one of the following compounds:



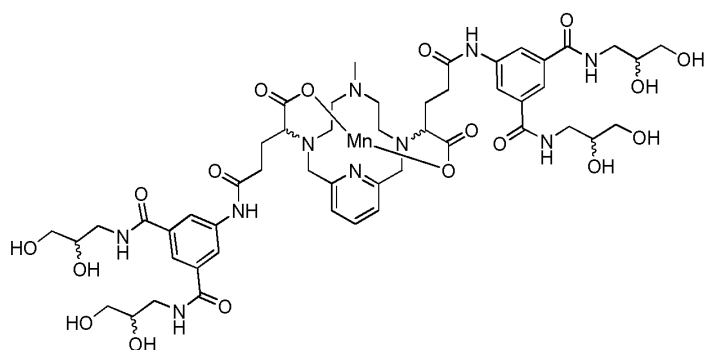
Mn Chelate 3



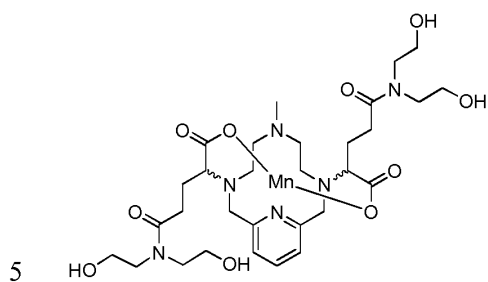
Mn Chelate 4



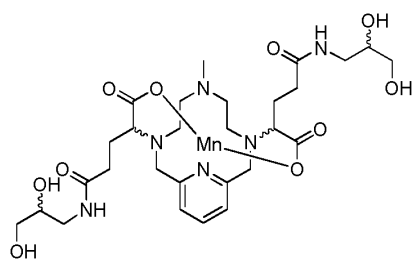
Mn Chelate 5



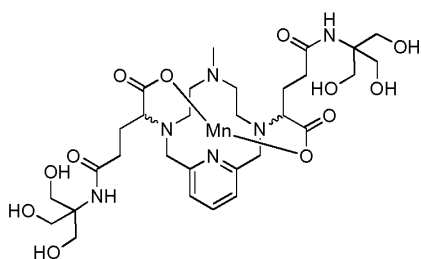
Mn Chelate 7



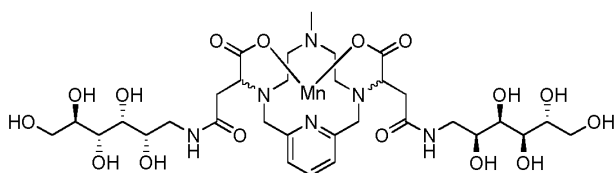
Mn Chelate 9



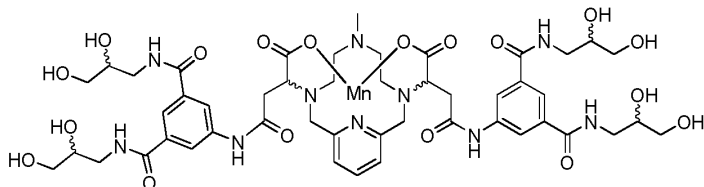
Mn Chelate 10



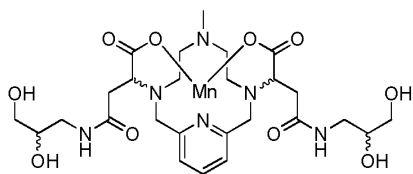
Mn Chelate 11



Mn Chelate 5a



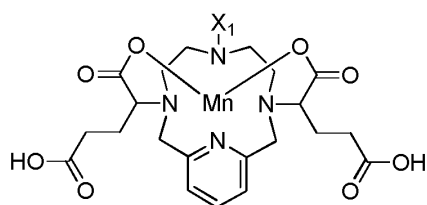
Mn Chelate 7a



Mn Chelate 10a

(42) A method for the preparation of a compound of Formula I as defined in any one of Claims 1-41 comprising:

- 10 (i) activating the carboxylate groups of a compound of Formula II with a peptide reagent

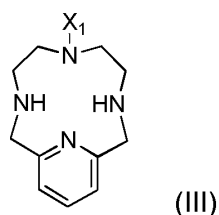


(II); then,

(ii) coupling said activated compound of Formula II with an amine derivative of substituent $-NR^1R^2$ to arrive at said compound of Formula I wherein R^1 and R^2 are as defined in Claim 1.

(43) The method as defined in Claim 42 wherein said peptide reagent is selected from 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide (EDCI) or hydroxybenzotriazole (HOBT).

(44) A method for the preparation of a compound of Formula II as defined in Claim 42 comprising alkylation of a compound of Formula III:



wherein X_1 is methyl or $-(CH_2)_3-COOH$

(45) A pharmaceutical composition comprising the compound of Formula I as defined in any one of Claims 1-41 together with a biocompatible carrier in a form suitable for mammalian administration.

(46) The pharmaceutical composition as defined in Claim 45 further comprising one or more pharmaceutically-acceptable excipients.

(47) The pharmaceutical composition as defined in Claim 46 wherein said pharmaceutically-acceptable excipients are selected from buffering agents, stabilizers, antioxidants, osmolality adjusting agents, pH adjusting agents, excess chelant and weak complexes of physiologically tolerable ions.

(48) A method comprising:

(i) administration to a subject of the compound of Formula I as defined in any one of Claims 1-41 or the pharmaceutical composition as defined in any one of Claims 45-47;

(ii) detection of magnetic resonance (MR) signals from said subject or parts of said subject in which said compound has distributed;

(iii) generation of MR images and/or MR spectra from said detected

signals.

(49) The compound of Formula I as defined in any one of Claims 1-41 for use in the method as defined in Claim 48.