Review Article

Role of chelates in treatment of cancer

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Abstract

Chelates are used in cancer as cytotoxic agent, as radioactive agent in imaging studies and in radioimmunotherapy. Various chelates based on ruthenium, copper, zinc, organocobalt, gold, platinum, palladium, cobalt, nickel and iron are reported as cytotoxic agent. Monoclonal antibodies labeled with radioactive metals such as yttrium-90, indium-111 and iodine-131 are used in radioimmunotherapy. This review is an attempt to compile the use of chelates as cytotoxic drugs and in radioimmunotherapy.

Key words: Chelates, cytotoxic agent, radioimmunotherapy

Introduction

Trace quantities of several metals are essential constituents of the human body. This is because the activity of many enzymes depends on these metal ions. Though the amount of metals present in human body is approximately 0.3% of the body weight, but excess of any metal is harmful to the body. With industrial and technological advancements, metal pollution in the atmosphere has been increasing fast. Increased proportion of trace metals in atmosphere have laid down some serious toxic effects. One of the major toxicity induced by these metals is their ability to behave as carcinogens. Metals belong to the category of pro-carcinogens. These are chemicals that require metabolic activation for becoming potent 'ultimate' carcinogen. They are activated by mixed oxidase of cytochrome P-450 system located in the microsomal components of the endoplasmic reticulum or the nucleus, thus forming pro-carcinogens. These substances become electron-deficient i.e. electrophiles and bind to electron-rich portions in DNA causing mutagenesis, finally leading to cancer, e.g. metals like nickel, chromium, etc. cause lung cancer.^[1]

Chelation refers to the formation of cyclic complex by coordination of a metal ion with a polydentate ligand. The resulting cyclic compound formed is known as a chelate. This complex formation results in precipitation of the metal or formation of a stable and a soluble compound. Controlled removal of undesirable metal ions can be achieved by the use of appropriate chelating agents.^[2] A considerable number of metal complex compounds are known to possess antitumor activity. It is assumed that they deactivate either the carcinogenic metal or the enzymes necessary for the rapid growth of both healthy and malignant cells.^[1]

Chelates can be useful in malignancy by the following ways:

- As cytotoxic drugs
- As radioactive agents in imaging studies
- In radioimmunotherapy (RIT)

This review is an attempt to compile the use of chelates as cytotoxic drugs and in RIT.

Chelates as Cytotoxic Agent

Many chelates are shown to possess cytotoxic activity. The most widely used complex in chemotherapy is cis-dichlorodiamine platinum(II). Some rhodium and iridium complexes and analogs of the active platinum complexes (platinum(IV) complexes: [Pt (dmgly) 2Cl₂], [Pt (sar) 2Br₂] and [Pt (dmgly) 2Br₂]) show antitumor activity. The role of tungstosilicic acid (TSA) as antitumor and antiviral agent is well established. From the data available on anticancer activity of metal chelates, it is generalized that:

- Metals used in such type of complexes should belong to group VII of the periodic table, like palladium, platinum, ruthenium and rhodium.
- Chelating agent should be lipophilic and should closely resemble a nutrient to ease its penetration in malignant cell across the cell membrane.
- The metal complex should be in *cis*-form.
- It should be sufficiently kinetically stable, so that it remains unchanged during circulation through body fluids.^[3]

The following section discusses some of the latest advancements in use of metal chelates as cytotoxic agents [Table 1].

Ruthenium-based chelates

 A series of mononuclear ruthenium complexes of the type [Ru(phen)₂(nmit)]Cl₂-(Ru1), [Ru(bpy)₂ (nmit)]Cl(2)-(Ru2), [Ru(phen)(2)(icpl)]Cl(2)-(Ru3), Ru(bpy)(2)(icpl)]Cl(2)-(Ru4){phen = 1, 10-phenanthroline; bpy = 2,2'-bipyridine; nmit =

Metal	Ligand	Indication	Mechanism of action
Rhuthenium-based chelates		22x	
Ruthenium (II)	 (1,10-phenanthroline)2N-methyl-isatin-3 thiosemicarbazone Cl₂ (2,2'-bipyridine)2N-methyl-isatin-3 thiosemicarbazone Cl₂ (1,10-phenanthroline)isatin-3-(4-Cl-phenyl) thiosemicarbazone Cl₂ (2,2'-bipyridine)isatin-3-(4-Cl-phenyl) thiosemicarbazone Cl₂ 4-Cl-phenyl 4-Br-phenyl 	Ehrlich ascetes carcinoma (EAC)	Selective alkylation of nucleobases in DNA by strong hydrogen bonding
Ruthenium (III)	N,N-dimethylglycine chloro	Astrocytomas	
Ruthenium (II)	1,10-phenanthroline 2,2'-bipyridine	Lymphocytic leukemia	
Ruthenium (II)	2-formylpyridine (4-H/4-phenyl) thiosemicarbazone	Lymphoma, Mammary carcinoma	
Ruthenium (II)	Bis(1,10-phenanthroline/2,2'-bipyridine)	EAC	
Ruthenium (II)	Bis(2-phenylazopyridine)	Ovarian carcinoma	
Ruthenium (III)	N,N-dimethyl glycine, chloro ligand	Astrocytomas	
Ruthenium (II)	Organometallic ligand	Anticancer	Arene-nucleobase stacking cytostatic and cytotoxic effects through p53- dependent and p53- independent mechanisms
Copper-based chelates			
Copper (II)	Phenylglyoxal bis(4-methyl-3- thiosemicarbazone	Cytotoxic	Induction of apoptosis
Copper (II)	Di-Schiff bases	Cytotoxic	Catalyze production of hydroxyl radicals in the presence and absence of TPA-activated polymorphonuclear leukocytes, leading to reduction in tumor size, delay of metastasis and increase in host survival
Copper (II)	N 1-isonicotinoyl-3-methyl-4- (p-hydroxybenzilidene)-2- pyrazolin 5-one (IMHBP)	Antitumor	Induction of apoptosis
Copper (II)	Synthetic curcuminoids	Cytotoxic	Reduction in tumor size, delay of metastasis and increase in hosts survival

Table 1 (Continued)

Metal	Ligand	Indication	Mechanism of action
Copper (II)	N-Salicyloyl-N'-p-hydroxythiobenzohydrazida and N-benzoyl-N'-thiobenzohydrazide	Dalton's Lymphoma	Inhibition of 3H- thymidine and 3H-uridine incorporation in DNA and RNA, respectively
Copper (II)	L-ascorbic acid, o-phenanthroline, 2,9-dimethyl-o-phenanthroline	Endometrial carcinoma	Apoptosis, reduction in tumor size, delay of metastasis
Copper (II)	Nitrilotriacetic acid	Antitumor	Induction of apoptosis
Copper (II)	N-Nicotinoyl-N'-o-hydroxythiobenzhydrazide	Antitumor	Apoptosis
Copper (II)	N'-[(2-hydroxy phenyl) carbonothioyl] pyridine-2-carbohydrazide	Colon cancer	Inhibits the expression of c-Src, a non-receptor tyrosine kinase that mediates growth signaling pathway
Copper (I)	Tris(hydroxymethyl) phosphine containing bis(1,2,4-triazol-1-yl)acetate co ligand	Antitumor	Trigger paraptosis, a non- apoptotic mechanism of cell death
Copper (I) phosphane	Dihydridobis(3-nitro-1,2,4-triazolyl)borate	Cytotoxic	Induces cell cycle arrest and apoptosis
Copper (I)	1,2-bis(diphenylphosphino)ethane	Cytotoxic	Induction of apoptosis
Copper (II)	Trans-bis(salicylaldoximato)	Cytotoxic	Induces cell cycle arrest
Copper (II)	Doxorubicin	Cytotoxic	Apoptosis
Zinc-based chelates		·	
Zinc (II)	Phenylglyoxal-bis-(4-methyl-3- thiosemicarbazone)	Ehrlich ascites tumor	Induces DNA ladder formation
Zinc (II)	Beta-thujaplicin, beta-thujaplicin	Malignant Melanoma	Induces DNA ladder formation and apoptosis
Gold-based chelates			
Gold (I)	bis(di-phosphino)	Leukemia, Sarcoma and Melanoma	Antiproliferative effects and DNA binding properties
Gold (I)	Monophosphine and diphosphine	Non-small lung, colon, CNS, renal, prostate, breast and ovarian cancer	Antiproliferative effects
Gold (III)	Methylsarcosinedithiocarbamate	Human acute myeloid leukemia	Antiproliferative and apoptotic effects
Gold (III) oxo complex	Bipyridyl ligand	Human ovarian carcinoma	Antiproliferative effects and DNA and protein binding properties
Gold (III)	N,N-dimethyldithiocarbamate and ethylsarcosinedithiocarbamate	Cytotoxic	Antiproliferative effects
Platinum-based chelates			
Platinum (II)	N,N-bis(phosphonomethyl)glycine	Cytotoxic	Ability to bind with DNA and induction of apoptosis
Platinum (II) and (IV)	Cis-bis-(2-chloroethylamine)	Cytotoxic	
Platinum (II)	Cis-diammine-1,1-cyclobutane dicarboxylate	Leukemia and ovarian tumor	
Platinum (II)	Cyclopentanecarboxylic acid hydrazide	Cytotoxic	
Platinum (II) and (IV)	1,3-diaminepropane and 1,4-diaminebutane	Ovarian tumor	

Table 1 (Continued)

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Table 1: (Continued)					
Metal	Ligand	Indication	Mechanism of action		
Platinum (II)	2-benzoylpyrrole	Cytotoxic			
Platinum (IV)	1,4-butanediamine	Leukemia, Melanoma			
Platinum (II)	cis-Dichloro-bis(2-aminohexadecanol	Cytotoxic			
Platinum (II) and (IV)	Transamine dichlorodihydroxo and tetrachloro	Plasmacytoma and advanced stage human ovarian carcinoma			
Platinum (II)	Diaminocarboxylic acids (D,L-2,3- diaminopropionic acid and D,L-2,4- diaminobutyric acid) and their ethyl ester derivatives	Cytotoxic			
Platinum (II)	[2-substituted-4,5-bis(aminomethyl)- 1,3-dioxolane]	Cytotoxic	Induction of apoptosis		
Platinum (II)	[(2R)-aminomethylpyrrolidine](1,1- cyclobutanedicarboxylate	Cytotoxic			
Palladium-and platinum-based	chelates				
Platinum (II) and Palladium (II)	6-mercaptopurine and thioguanine	Lymphoid Ieukemia	Apoptosis		
Palladium (II)	Diaminosuccinic acid and its diethyl esters	Antitumor	Apoptosis		
Miscellaneous	× ~ ~ ~ ~	2.			
Cobalt (II) and Nickel (II)	5-dimethylaminomethyl-2-thiouracil	Antitumor	Antiproliferative effects		
Fe (II), Ni (II), Cu (II), Zn (II) and Pt (II)	S-methyl-N-(I-isoquinolyl) methylendithiocarbazate	Antitumor	Apoptosis		
Cobalt (II), copper (II), nickel (II) and zinc (II)	Furanylmethyl- and thienylmethyl-dithiolenes: [1,3-dithiole- 2-one and 1,3-dithiole-2-thione]	Cytotoxic	Apoptosis		

N-methyl-isatin-3 thiosemicarbazone, icpl = isatin-3-(4-Cl-phenyl)thiosemicarbazone}4-Cl-phenyl-(Ru10) and 4-Br-phenyl-(Ru11) show significant antitumor activity without adversely affecting the hematological profiles. They remarkably decreased the tumor volume, viable ascetic cell count and prolonged the lifespan of Ehrlich Ascetes Carcinoma (EAC) bearing mice. Tumor inhibition by the ruthenium chelates was followed by improvements in hemoglobin, RBC and WBC values.^[4]

- Bis(1,10-phenanthroline/2,2'-bipyridine) ruthenium(II) complexes contain 1-thiocarbamoyl-3,5-diphenyl-2-pyrazoline, 2-(3,5-diphenyl-4,5-dihydropyrazol-1-yl)-4-phenylthiazole, 2-hydroxyphenyl benzimidazole and benzoin thiosemicarbazone ligands coordinated with the metal through nitrogen, sulfur and oxygen atoms. They were shown to exhibit significant antitumor activity in EAC-bearing mice.^[5]
- 3. New water-soluble bis(2-phenylazopyridine) ruthenium(II) complexes, namely 1,1cyclobutanedicarboxylatobis(2-phenylazopyrid ine)ruthenium(II), alpha-[Ru(azpy)(2)(cbdca-O,O')](1), oxalatobis(2-phenylazopyridine)ru

thenium(II), alpha-[Ru(azpy)(2)(ox)](2) and malonatobis(2-phenylazopyridine)ruthenium(II), alpha-[Ru(azpy)(2)(mal)](3) display promising cytotoxicity with an activity comparable to that of cisplatin and even higher than the activity of carboplatin. Results further suggest that the activity of these compounds might not be influenced by the resistance mechanism that affects platinum anticancer agents.^[6]

- 4. A novel class of ruthenium(III) complex of formulae K₂[Ru(dmgly)Cl₄].2H₂O, containing bidentate chelates N,N-dimethylglycine (dmgly) and additional chloro ligand, markedly inhibited the viability of non-confluent C6 cells and confluent C6 cultures. Importantly, this complex was not toxic to primary rat astrocytes or macrophages, thus behaving as promising agent for developing drugs against astrocytomas.^[7]
- 5. Fully coordinated 1,10-phenanthroline and 2,2'-bipyridine chelates of Ru(II) are lethal to lymphocytic leukemic cells. Lethal potency is greatest for Ru(II) chelates containing highly alkylated ligands.^[8]
- 6. A group of four ruthenium chelates of the mixed hard/soft N-S donor ligand 2-formylpyridine

(4-H/4-phenyl) thiosemicarbazone, namely bis[2formylpyridine(phenyl)thiosemicarbazone]ruthenium(II)chloride], [2-formylpyridine(4-phenyl) thiosemicarbazone] Ruthenium(II)-trichloro (imidazole)ruthenium(III) monomethanolate, [2-formylpyridine(4-phenyl)thiosemicarbazone] dichloroimidazole ruthenium (II) and bis[2-formylpyridinethiosemicarbazone]ruthenium (II) perchlorate dihydrate were synthesized. Bis-chelates possessed greater cytotoxic properties toward primary tumor than the monochelates. The presence of two chelate rings around the ruthenium(II)/(III) acceptor center or the increase in the number of the soft (S) donor centers generate greater cytotoxic property in the corresponding ruthenium complexes.^[9]

7. Organometallic ruthenium(II) complexes of the type [(eta(6)-arene)Ru(X)(Y)(Z)], where arene is benzene or substituted benzene; X, Y and Z are halide, acetonitrile or isonicotinamide or X, Y is ethylenediamine (en) or N-ethylethylenediamine were shown to have DNA binding properties; thus exhibiting anticancer activity.^[10] These compounds show arene-nucleobase stacking and stereo-specific hydrogen bonding in guanine adducts.^[11] They also induce cytostatic and cytotoxic effects on mammalian cancer cell lines through p53-dependent and p53-independent mechanisms.^[12]

Copper(II)-based chelates

- 1. Substituted [phenylglyoxal bis(4-methyl-3thiosemicarbazone)] copper(II) chelates show considerable cytotoxic activity. Electron-donating substituent enhanced the water solubility resulting in increased cytotoxicity.^[13]
- 2. Anticarcinogenic activity of copper di-Schiff bases (two novel di-Schiff bases coordinated with active center analogs of Cu₂Zn₂ superoxide dismutase) effectively catalyzes the production of hydroxyl radicals in the presence and absence of TPA-activated polymorphonuclear leukocytes, thus leading to reduction in tumor size, delay of metastasis and a significant increase in survival of the hosts.^[14] In addition, Cu-67 chelates labeled with antibodies are developed and peptide linkers lead to modification of liver metabolism and improved tumor targeting of copper-67 labeled antibody fragments.^[15]
- 3. Copper(II) complexes of N-1-isonicotinoyl-3methyl-4-(p-hydroxybenzilidene)-2-pyrazolin-5-one (IMHBP) also show considerable activity against tumor. For the formation of these chelates, squareplanar structure was assigned to the copper(II) complex. IMHBP acts as a neutral bidentate ligand in all these complexes by coordinating through the oxygen atoms of the amide group and carbonyl

at position 5. Anions alone or anions and water molecules satisfy the other coordination sites.^[16]

- 4. Copper chelates of synthetic curcuminoids show enhanced antitumor activity. Four synthetic curcuminoids, 1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione(curcumin-1); 1.7bis(piperonyl)-1,6-heptadiene-3,5-dione(piperonyl curcumin); 1,7-bis(2-hydroxy naphthyl)-1, 6-heptadiene-2,5-dione(2-hydroxy naphthyl curcumin); 1,1-bis(phenyl)-1,3,8,10-undecatetraene-5,7-dione(cinnamyl curcumin), and their copper(II) complexes were investigated for their possible cytotoxic and antitumor activities. Copper complexes of curcuminoids with a hydroxy group on the ring such as 2-hydroxy naphthyl curcumin were found to be most active. Copper complex of cinnamyl curcumin, which has an extended conjugation, showed considerable activity in increasing the life span (ILS = 78.6%) of ascites tumor bearing animals, whereas complex of piperonyl curcumin showed least antitumor activity. Copper chelates of curcuminoids showed a significant reduction (P < 0.001) of solid tumor volume in mice.^[17]
 - Copper(II) complexes of N-Salicyloyl-N'-phydroxythiobenzohydrazide and N-benzoyl-N'thiobenzohydrazide show significant inhibition of 3H-thymidine and 3H-uridine incorporation in DNA and RNA, respectively. In-vivo administration of these complexes resulted into prolongation of life span of Dalton's Lymphoma (DL) bearing mice.^[18] L-ascorbic acid inhibits the growth of mouse neuroblastoma and human endometrial carcinoma cells at concentrations greater than 100 µM. The antitumor activity of ascorbate can be greatly potentiated by combination with copper ions. The exposure of normal and tumor cells to the mixtures of ascorbate and copper chelates, especially Cu2+-o-phenanthroline and Cu2+-2,9-dimethyl-ophenanthroline complexes resulted in the killing of a large proportion of cell populations. These copper chelates in combination with ascorbate showed different degrees of DNA-scission and antiproliferative activity.^[19] In addition, mixed chelate copper-based anticancer drug, casiopeinas, was found to bind to DNA and degrade DNA and RNA in the presence of reducing agents, e.g. ascorbic acid.^[20]
- 7. Exogenous copper in the form of chelate increases the growth of a copper-requiring tumor system. The growth promoting activity of exogenous copper in the B16 melanoma system involves both enhanced copper nutrition and concomitant alteration of host reactions to tumors.^[21] This exception was observed in cuprous chelate of neocuproine (NC-Cu⁺¹) that enhanced tumorogenicity of s.c. tumors.^[21,22] But,

cupric chelate of nitrilotriacetic acid (NTA-Cu²⁺) inhibited pigmentation in s.c. tumors.^[21] Further, it was concluded that the growth-promoting activity of NC-Cu⁺¹ on tumors is related to the oxidation state of copper in chelates and enhanced copper nutriture of tumors.^[22]

- 8. Copper(II) complex of N'-[(2-hydroxy phenyl) carbonothioyl] pyridine-2-carbohydrazide inhibits the expression of c-Src, a non-receptor tyrosine kinase, which plays a significant role in the growth-mediated signaling pathway, thus showing cytotoxicity against the colon cancer cell line.^[23]
- 9. Tris-(hydroxymethyl)phosphine copper(I) complexes containing the new bis(1,2,4-triazol-1-yl)acetate ligand showed *in-vitro* antitumor activity similar or better than that of cisplatin, the most used metal-based antitumor drug. Copper(I) complexes were able to overcome cisplatin resistance, supporting the hypothesis of a different mechanism of action compared to that exhibited by the reference drug. It is hypothesized that the cytotoxic activity of the new copper(I) complex may be correlated to its ability to trigger paraptosis, a non-apoptotic mechanism of cell death.^[24]
- 10. Cytotoxic effects are shown by copper(I) phosphane complexes of dihydridobis(3-nitro-1,2,4-triazolyl)borate,^[25] copper(II) complex of N-Nicotinoyl-N'-o-hydroxythiobenzhydrazide,^[26] copper(II)-doxorubicin chelate^[27] and copper(I) complexes of 1,2-bis(diphenylphosphino) ethane (DPPE).^[28] Copper(II) chelate of transbis(salicylaldoximato) showed cytotoxicity comparable to that of adriamycin by inducing cell cycle arrest and apoptosis.^[29]

Zinc-based chelates

- 1. Substituted phenylglyoxal-bis-(4-methyl-3thiosemicarbazone) zinc chelates behave as potential antineoplastic agents. Fourteen para-substituted phenylglyoxal-bis-(4-methyl-3-thiosemicarbazone) zinc chelates were shown to be cytotoxic against Ehrlich ascites tumor cells. Quantitative comparative analysis suggests that this selective action against the tumor cell system can be improved by substitution with groups having electron withdrawing and lipophilic nature.^[30]
- 2. Beta-thujaplicin metal chelates act as promising anticancer agents. The cytotoxic effects of betathujaplicin and five kinds of metal chelates were examined on mouse melanoma B16BL6 cells by cell viability and lactate dehydrogenase (LDH) release assay. Beta-thujaplicin-zinc chelate and betathujaplicin-copper chelate had higher cytotoxic effects than beta-thujaplicin. In addition, the zinc chelate induced DNA ladder formation; as shown

by the DNA fragmentation assay, suggesting that cell death induced by the zinc chelate is apoptosis. These chelates induce apoptotic cell death in various other tumor cell lines also. Thus, it is a potent antitumor agent for tumor cells including malignant melanomas.^[31]

Gold(I)-based chelates

- 1. Some tetrahedral bis(di-phosphino) gold(I) chelates were found to be most active against P388 leukemia, M5076 sarcoma and B16 melanoma. Chelates were ionic, tetrahedral, bischelated gold diphosphine complexes of the type $[Au1(R_2PYPR_{2'})_2]X$, where $Y = (CH_2)_2$, $(CH_2)_3$ or cis-CH = CH. The anion $(X = Cl, Br, I, CH_3SO_3, NO_3, PF_6)$ had little effect upon activity.^[32]
- 2. Antitumor agents gold-monophosphine and golddiphosphine derivatives show activity against nonsmall lung, colon, CNS, renal, prostate, breast and ovarian cancer.^[33]
- 3. Two newly synthesized gold(III) derivatives of methylsarcosinedithiocarbamate, containing a sulfur chelating ligand that is able to bind the metal center strongly acts as a potent anticancer agent against human acute myeloid leukemia cells by exerting antiproliferative and apoptotic effects.^[34]
- 4. Six dinuclear gold(III) oxo complexes with bipyridyl ligands showed *in-vitro* antitumor effects against human ovarian carcinoma cell line due to antiproliferative effects and DNA- and proteinbinding properties.^[35]
- 5. Gold(III) derivatives of N,N-dimethyldithiocarbamate and ethylsarcosinedithiocarbamate proved to be much more cytotoxic *in-vitro* than cisplatin and rules out the occurrence of cross-resistance phenomena.^[36]

Organocobalt(III)-based chelates

Organocobalt(III) chelates containing a sigma-bonded organyl group and a mixed tridentate ligand derived from a Schiff base are proposed for combined cancer therapy. These complexes generate free radicals due to the action of protons in physiological ranges of pH and temperature and hence are conceivably capable of selectively attacking a malignant neoplasm that is slightly acidic and can be made even more by introducing some means of intensifying glycolysis.^[37]

Platinum-based chelates

Diamine platinum(II) complexes bearing an N,Nbis(phosphonomethyl) glycine ligand,^[38] cis-bis-(2chloroethylamine) platinum(II) and platinum(IV) complexes,^[39] cis-diamine-1,1-cyclobutane dicarboxylato platinum(II) complexes show significant activity against leukemia and ovarian tumor.^[40] Platinum(II) complexes of cyclopentanecarboxylic acid hydrazide^[41] and platinum(II) and (IV) complexes of 1,3-diaminepropane and 1,4-diaminebutane were found active against ovarian tumor cells.^[42] Platinum(II) complexes of 2-benzoylpyrrole^[43] and octahedral (1,4-butanediamine) platinum(IV) complexes were found active against L1210 leukemia/B16 melanoma.^[44] Lipophilic cisdichloro-bis(2-aminohexadecanol) platinum(II) complex^[45] and transamine dichlorodihydroxo platinum(IV) and tetrachloroplatinum(IV)/(II) complexes show significant activity against murine plasmacytoma and advanced stage human ovarian carcinoma.[46] The other platinum-based chelates reported to possess cytotoxic activity are platinum(II) complexes of diaminocarboxylic acids (D,L-2,3-diaminopropionic acid and D,L-2,4-diaminobutyric acid) and their ethyl-ester derivatives,^[47] [2-substituted-4,5-bis(aminomethyl)-1,3-dioxolane] platinum(II) complexes^[48] [(2R)aminomethylpyrrolidine](1,1-cyclobutanedicarboxylato) platinum(II) complexes^[49] and polynuclear platinum(II) chelates with biogenic polyamines.[50] The platinumbased chelates were reported to have significant activity against leukemia and ovarian tumors. The reported mode of action is their ability to bind with DNA and inhibition of apoptosis.

Palladium- and platinum-based chelates

- Cytotoxic action of palladium and platinum complexes^[51] of 6-mercaptopurine and thioguanine – Pd(MP)₂·2H₂O, Pt(MP)₂H₂O (MPH = 6-mercaptopurine), Pt(AMP)₂·3H₂O and Pd₃(AMP)4Cl₂(AMPH)·4H₂O (AMPH = thioguanine) – showed marked antitumor activity against L-1210 lymphoid leukemia test system.^[52]
- 2. Cis-dichloropalladium(II) complexes with diaminosuccinic acid and its diethyl esters show significant antitumor activity against human cancer cell lines.^[53,54]

Miscellaneous chelates

1. Cobalt and nickel chelates of 5-dimethylaminomethyl-

2-thiouracil were found more active than the parent compound. Cobalt(II) complexes were found to be four coordinates, among which the bromo, iodo and nitrato complexes were polymeric. The nickel(II) isothiocyanato complex exhibited fourcoordinate geometry and the remaining nickel(II) complexes were six coordinates. The order of activity was influenced by the chelate geometry and thermal stability. The activity increased with a decrease in coordination number and increase in thermal liability.^[55]

2. Cobalt(II), copper(II), nickel(II) and zinc(II) complexes with furanylmethyl- and thienylmethyl dithiolenes [1,3-dithiole-2-one and 1,3-dithiole-2-thione] show prominent cytotoxic activity.^[56]

Chelates in RIT

Radioimmunotherapy^[51] is a promising approach for treating metastatic breast cancer and non-Hodgkin's lymphoma (NHL). Approximately 55,400 new cases of NHL are diagnosed each year, with the overall prevalence of the disease now estimated to be 243,000. Based on the results of several clinical trials, the chimeric monoclonal antibody Rituximab has now been approved by the US-FDA for treatment of patients with relapsed or refractory, low-grade or follicular, B-cell NHL. Several other monoclonal antibodies in conjugated and unconjugated forms have been evaluated in the treatment of NHL [Table 2]. Ibritumomab, the murine counterpart to Rituximab, radiolabeled with 90Y (Zevalin), is presently being evaluated in clinical trials. The success of RIT is dependent upon the appropriate choice of antibody, isotope and chelator-linker. The Ibritumomab antibody targets the CD20 antigen. The antibody is covalently bound to the chelatorlinker tiuxetan (MX-DTPA), which tightly chelates the isotope 90Y. To date, two Phase I/II Zevalin clinical trials have been completed in patients with low-grade, intermediate-grade and mantle cell NHL. The overall response rate was 64% in the first trial and 67% in

Table 2: Chelates reported in radioimmunotherapy					
Name	Туре	Indication	Mechanism of action		
Rituximab (Rituxan)	Chimeric monoclonal antibody	Lymphoma, metastatic breast cancer	Binds to CD20 molecule found on $\beta\text{-cells}$		
lbritumomab Tiuxetan (Zevalin)	Monoclonal antibody conjugated either to Indium-111 or Yttrium-90	Non-Hodgkin's lymphoma	Binds to CD20 molecule on $\beta\mbox{-cells}$ and lymphoma		
Tositumomab (Bexxar)	Monoclonal antibody conjugated to I-131	Non-Hodgkin's lymphoma	Binds to CD20 molecule expressed on normal β-cells		
1311 Lym-1 (Oncolym)	Monoclonal antibody conjugated to I-131	β-cells non-Hodgkin's lymphoma	Binds to HLA-DR encoded histocompatibility Ag expressed at high levels on lymphoma cells		

the later trial. Phase II and III trials are ongoing.^[57] Yttrium-90 Ibritumomab tiuxetan (IDEC-Y2B8) is a murine immunoglobulin G1 kappa monoclonal antibody that covalently binds MX-DTPA (tiuxetan), which chelates the radioisotope yttrium-90. The antibody targets CD20, a B-lymphocyte antigen Zevalin, which consists of a murine anti-CD20 monoclonal antibody (Ibritumomab), conjugated to the linker-chelator tiuxetan, which securely chelates 111-Indium for imaging and dosimetry and yttrium-90 for RIT.^[58] Previous trials involving rituximab-naive patients have demonstrated excellent targeting of Zevalin to CD20+ B-cell NHL with minimal uptake in normal organs. Zevalin treatment of rituximab-refractory follicular NHL patients at 0.4 mCi/kg resulted in acceptable estimates of absorbed radiation dose to organs, similar to those observed in other Zevalin-treated populations.^[59]

90Y-labeled humanized LL2 (hLL2) monoclonal antibody (mAb) prepared with the DOTA chelate represents an improved agent for RIT of NHL, with an *in-vivo* model demonstrating a large reduction in bone-deposited yttrium, as compared with 90Y-hLL2 agents prepared with open-chain DTPA-type chelating agents. Dosimetry suggests that this benefit will result in a substantial toxicologic advantage for a DOTA-based hLL2 conjugate.^[60]

Initial clinical trials using 131-I radioimmunoconjugates and more recent studies employing 90Y have demonstrated objective, although transient, antitumor effects in heavily pretreated metastatic breast cancer patients with minimal toxicity. Antibodies targeting unique epitopes of epithelial glycoprotein mucin (MUC-1) on breast cancer cell surfaces that have been studied in patients include BrE-3 (murine and humanized) and m170 (murine). Both antibodies react with at least 90% of breast cancers. In these and other RIT trials, myelosuppression has been the dose-limiting toxicity. However, this toxicity has been successfully circumvented with the use of autologous peripheral blood stem cell transplantation, and recent clinical trials have escalated 90Y doses up to 50 mCi/m(2).^[61]

Conclusion

Chelates are inorganic agents that have good clinical effects in treatment of various types of cancer as cytotoxic agent and in RIT. It is suggested that they deactivate either the carcinogenic metal or the enzymes necessary for the rapid growth of both healthy and malignant cells. The *cis*-form of complex of metals belonging to group VII of the periodic table, such as palladium, platinum, ruthenium and rhodium, shows significant cytotoxic activity. The use of monoclonal antibodies labeled with radioactive metals, such as yttrium-90, indium-111 and iodine-131, in treatment of malignancies is an evolving field. New therapeutic approaches are rapidly emerging, and further research may help in designing more specific chelates that would spare the normal tissues, have less adverse effects and improve patient's quality of life.

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